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THE MINERAL RESOURCES OF THE NORTH WEST FRONTIER PROVINCE. By A. L. COULSON, D.Sc., D.I.C., F.G.S., F.N.I., *Superintending Geologist, Geological Survey of India.* Pages 1—55.

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THE MINERAL RESOURCES OF THE NORTH-WEST FRONTIER PROVINCE.

By A. L. COULSON, D.Sc., D.I.C., F.G.S., F.N.I., *Superintending Geologist, Geological Survey of India.*

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INTRODUCTION.

This short note has been written primarily to supply the Developments Department of the Government of the North-West Frontier Province with an idea of the mineral resources of the Province and to indicate the directions to which activities could be turned for its future economic development. It does not claim to be detailed and must be regarded as a summarised account of a subject which I have long hoped to deal with more fully, but have been prevented from so doing by pressure of more urgent work.

UNPUBLISHED REPORTS.

The following is a list of the chief unpublished reports on matters of economic importance in the North-West Frontier Province which officers of the Geological Survey of India have written during recent years. Most of these were forwarded to the Chief Secretary of the Local Government.

G. DE P. COTTER, FEBRUARY, 1926.	"Note on the Geology of the Kurram Valley."
A. L. COULSON, 30-1-1936.	"Preliminary Report on the Clay of the Besai Ridge."

A. L. COULSON,	10-2-1936 .	"Preliminary Report on the Paniala Clay."
,,	13-2-1936 .	"Report on the Kark (Kharak) Oil-Shale, Kohat District."
,,	15-2-1936 .	"Preliminary Report on Gold in the North-West Frontier Province."
,,	30-3-1936 .	"The Marbles of the Mullagori Country, Khyber Agency and of the Peshawar District, North-West Frontier Province: with an Appendix on the Slates of the Nowshera Tahsil, Peshawar District." [Much of this was published in my paper "Marble of the North-West Frontier Province", *Rec. Geol. Surv. Ind.*, 71, Pt. 3, pp. 328-344, (1936).]
,,	1-4-1936 .	"Report on the Steatite of Khairabad Kund, Nowshera Tahsil: with an Appendix on the Clay at Jahangira, Swabi Tahsil."
,,	13-8-1936 .	"Oil-Shale near Banda Daud Shah, Kohat District, North-West Frontier Province."
,,	2-10-1936 .	"Preliminary Report on the Economic Geology of Waziristan, North-West Frontier Province."
,,	25-2-1937 .	"The Relation of the Coal of the Surghar Range to the Boundary between the Kohat District of the North-West Frontier Province and the Mianwali District of the Punjab."
,,	7-7-1937 .	"The Coal of the Dore River, near Abbottabad, Hazara District, North-West Frontier Province."
,,	30-7-1937 .	"Marble and Dolomite of Ghundai Tarako, a Hill forming part of the Frontier between the Swabi Tahsil of the Mardan District and the Buner Tract of Swat in the North-West Frontier Province." [Partly modified

	and published as "Marble and Dolomite of Ghundai Tarako, North-West Frontier Province", *Rec. Geol. Surv. Ind.*, 72, Pt. 2, pp. 227-234, (1937).]
A. L. Coulson, 30-12-1938	"The Sinking of Tube-Wells for the Electricity Department of the North-West Frontier Province at the Grid Sub-Stations at Mardan, Nowshera and Charsadda."
" 3-1-1939 .	"The Underground Water-Supply of the Peshawar and Mardan Districts of the North-West Frontier Province." (The report was enlarged and published as "The Underground Water-Supply of the Peshawar and Mardan Districts of the North-West Frontier Province; with an Appendix on the Kohat Valley," *Rec. Geol. Surv. Ind.*, 74, Pt. 2, pp. 229-239.)
" 30-3-1939 .	"The Water-Supply of the Jarman Estate and of the Togh Area, Kohat District, North-West Frontier Province."
" 28-6-1939 .	"Gold in the Khyber Agency, North-West Frontier Province."
G. H. Tipper . . .	"Preliminary Report on Minerals in Chitral."
W. D. West, 11-8-1934 .	"Report on various Water-Supply Problems in the Peshawar Distirct."

PUBLISHED PAPERS.

The following is a list of the more important published papers and notices of an economic aspect that deal with the North-West Frontier Province, either entirely or in part :—

A. L. Coulson, 1936 .	"Marble of the North-West Frontier Province." *Rec. Geol. Surv. Ind.*, 71, Pt. 3, pp. 328-344.

A. L. COULSON, 1937 . "Marble and Dolomite of Ghundai Tarako, North-West Frontier Province." *Op. cit.*, 72, Pt. 2, pp. 227-234.

" " . "Gold in the North-West Frontier Province." *Trans. Min. Geol. Met. Inst. Ind.*, XXXIII, Pt. 2, pp. 191-206.

" 1939 . "The Underground Water-Supply of the Peshawar and Mardan Districts of the North-West Frontier Province; with an Appendix on the Kohat Valley." *Rec. Geol. Surv. Ind.*, 74, Pt. 2, pp. 229-259.

H. CROOKSHANK, 1939 . "Indian Refractory Clays." *Bull. Ind. Indus. Res.*, No. 14, pp. 34-35.

L. M. DAVIES, 1926 . "Notes on the Geology of Kohat." *Journ. A. S. B.*, N. S., XX, p. 207.

L. L. FERMOR, 1922 . "General Report for 1921." (Chitral: Arsenic-ore.) *Rec. Geol. Surv. Ind.*, LIV, p. 16.

" " . "General Report for 1921." (Chitral: Cinnabar.) *Op. cit.*, p. 26.

" " "General Report for 1921." (Chitral: Sulphide-ores.) *Op. cit.*, p. 30.

E. R. GEE, 1938 . "The Economic Geology of the Northern Punjab, with notes on adjoining portions of the North-West Frontier Province." *Trans. Min. Geol. Met. Inst. Ind.*, XXXIII, pp. 263-354.

A. M. HERON, 1937 . "General Report for 1936." (Geological Survey in North-West Frontier Province.) *Rec. Geol. Surv. Ind.*, 72, p. 71.

" " . "General Report for 1936." (Gold in Peshawar District.) *Op. cit.*, p. 50.

" " . "General Report for 1936." (Iron-ore in South Waziristan.) *Op. cit.*, p. 52.

" " . "General Report for 1936." (Irrigation Scheme in Khyber Agency.) *Op. cit.*, p. 47.

A. M. HERON, 1937 . "General Report for 1936." (Marble in North-West Frontier Province.) *Op. cit.*, p. 33.

" " . "General Report for 1936." (Nickel in North Waziristan.) *Op. cit.*, p. 53.

" " . "General Report for 1936." (Oil-shale in Kohat District.) *Op. cit.*, p. 54.

" " . "General Report for 1936." (Slate in North-West Frontier Province.) *Op. cit.*, p. 33.

" " . "General Report for 1936." (Soda-granite Suite in North-West Frontier Province.) *Op. cit.*, p. 28.

" " . "General Report for 1936." (Steatite in Peshawar District.) *Op. cit.*, p. 56.

" " . "General Report for 1936." (Upper Triassic Fossils in North-West Frontier Province.) *Op. cit.*, p. 35.

" " . "General Report for 1936." (Clay in North-West Frontier Province.) *Op. cit.*, p. 34.

" " . "General Report for 1936." (Coal in North-West Frontier Province.) *Op. cit.*, p. 44.

" " . "General Report for 1936." (Copper in North-West Frontier Province.) *Op. cit*, p. 45.

" 1938 . "General Report for 1937." (Geological Survey of Peshawar District.) *Op. cit.*, 73, p. 84.

" " . "General Report for 1937." (Coal in Dore River.) *Op. cit.*, p. 42.

" " . "General Report for 1937." (Coal in Hazara District.) *Op. cit.*, p. 36.

" " . "General Report for 1937." (Geological Survey of North-West Frontier Province.) *Op. cit.*, pp. 84 and 86.

" " . "General Report for 1937." (Hydro-Electric Possibilities in North-West Frontier Province.) *Op. cit.*, pp. 40-42.

A. M. HERON, 1938 . "General Report for 1937." (Marble in Mardan District.) *Op. cit.*, pp. 30 and 87.

" " . "General Report for 1937." (Coal from North-West Frontier Province and Punjab Boundary.) *Op. cit.*, p. 33.

" 1939 . "General Report for 1938." (Tube-Wells, Mardan, Nowshera and Charsadda.) *Op. cit.*, 74, pp. 42-43.

" " . "General Report for 1938." (Gold, Mardan District, North-West Frontier Province.) *Op. cit.*, p. 47.

" " . "General Report for 1938." (Mardan District, Geology.) *Op. cit.*, p. 64.

" " . "General Report for 1938." (Marble, Khyber Agency.) *Op. cit.*, p. 32.

T. H. D. LA TOUCHE, 1892. "Report on the Oil Springs at Moghal Kot in the Shirani Hills." *Rec. Geol. Surv. Ind.*, XXV, pp. 171-175.

C. S. MIDDLEMISS, 1890 . "Preliminary Note on the Coal Seam of the Dore Ravine." *Rec. Geol. Surv. Ind.*, XXIII, Pt. 4, pp. 267-269.

" 1896 . "The Geology of Hazara and the Black Mountain." *Mem. Geol. Surv. Ind.*, XXVI

E. H. PASCOE, 1920 . "Petroleum in the Punjab and North-West Frontier Province." *Mem. Geol. Surv. Ind.* XL, Pt. 3.

" 1923 . "General Report for 1922." (Chitral: Arsenic-ore.) *Rec. Geol. Surv. Ind.*, LV, p. 13.

" " . "General Report for 1922." (Chitral: Asbestos.) *Op. cit.*, p 14.

" " . "General Report for 1922." (Chitral: Copper-ore.) *Op. cit.*, p. 15.

" " . "General Report for 1922." (Chitral: Garnet.) *Op. cit.*, p. 19.

E. H. Pascoe, 1923 . "General Report for 1922." (Chitral: Manganese-ore.) *Op. cit.*, p. 15.

" " . "General Report for 1922." (Chitral: Sulphide-ores.) *Op. cit.*, p. 28.

M. Stuart, 1919 . . "The Potash Salts of the Punjab Salt Range and Kohat." *Rec. Geol. Surv. Ind.*, L, Pt. 1, pp. 28-56.

" " . "Suggestions regarding the origin and history of the rock-salt deposits of the Punjab and Kohat." *Rec. Geol. Surv. Ind.*, L, Pt. 1, pp. 57-99.

D. N. Wadia and L. M. Davies, 1929. . . "The Age and Origin of Gypsum associated with the Salt Deposits of Kohat." *Trans. Min. Geol. Inst. Ind.*, XXIV, pp. 202-222.

A. B. Wynne, 1875 . "The Trans-Indus Salt region in the Kohat district; with an Appendix on the Kohat Mines and Quarries by Dr. H. Warth." *Mem. Geol. Surv. Ind.*, XI, Pt. 2.

" 1880 . "On the Trans-Indus Extension of the Punjab Salt Range." *Mem. Geol. Surv. Ind.*, XVII, Pt. 2.

MINERAL PRODUCTION FROM FRONTIER PROVINCE.

In Tables 1 and 2 (p. 11), I give the recorded mineral production from the North-West Frontier Province, which from 1929 to 1938, had an annual average value of less than Rs. 75,000.

It will be seen that the mineral production of the Province is extremely small and consists almost entirely of salt, limestone, marble, and road-metal. Clays must be produced locally; but no figures of the production of these are available. Efforts should be made by the Local Government to obtain these and forward them regularly to the Geological Survey of India for inclusion in the annual returns of the mineral industry in India which are published in the *Records* of that Department.

TABLE 1.—*Mineral Production from North-West Frontier Province during the years 1929 to 1933.*

District.	Names of minerals.	1929.		1930.		1931.		1932.		1933.	
		Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
		Tons.	Rs.	Tons.	Rs.	Tons.	Rs.	Tons.	Rs.	Tons.	Rs.
Peshawar	Limestone	1,061	780	14,474	11,361	7,709	2,842	2,340	866	996	2,470
	Miscellaneous building material and road-metal.	..	.	3,869	1,741	244	94	4,283	1,654	3,349	4,592
Kohat	Rock-salt	19,625	63,068	23,005	73,176	21,123	66,509	19,972	62,796	20,577	65,116

TABLE 2.—*Mineral Production from North-West Frontier Province during the years 1934 to 1938.*

District or State.	Names of minerals.	1934.		1935.		1936.		1937.		1938.	
		Quantity.	Value	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
		Tons.	Rs.	Tons.	Rs.	Tons.	Rs.	Tons.	Rs.	Tons.	Rs.
Kohat	Rock-salt	19,138	60,125	21,003	64,708	18,226	56,322	20,655	64,167	20,698	62,810
Peshawar	Limestone	1,232	2,121	424	525	—	—	—	—	—	—
	Miscellaneous building material and road-metal.	—	—	—	—	18,132	11,852	1,604	3,625	18,190	21,739
Mardan	Ditto	—	—	14,359	(a)	12,422	(a)	..	..	6,372	(a)
Khyber Agency	Marble	..	..	(b) 48	500	(b) 2,190	23,000	(b) 571	7,000	95	1,000
Chitral	Zinckenite	..	.	..	..	..	..	(c)	..	(c)	..

(a) Value not reported.
(b) Figures relate to official years 1935-36, 1936-37 and 1937-38.
(c) Production amounted to 31 tons during 1937 and 1938. Value has not yet been determined.

SUMMARISED ACCOUNT OF THE OCCURRENCE OF MINERALS OF ECONOMIC IMPORTANCE.

In the following summarised account, I have refrained from giving references to relevant literature. If the reference cannot be found in the lists of unpublished reports and published papers accompanying this note, then the interested enquirer will doubtless find it in La Touche's invaluable "Annotated Index of Minerals of Economic Value", which forms Part I-B of his "Bibliography of Indian Geology and Physical Geography" (1918). I have summarised extensively from this useful publication.

Abrasives.

Chitral, etc.

Garnets are known to occur in Chitral, but they are cracked and only occasionally of good colour. They might be used as an abrasive were they found in sufficient quantity.

Hazara district.

There are abundant outcrops of white reef-quartz pegmatite associated with the Hazara granite-gneiss. The crushing of these is likely to be expensive.

Kohat district.

A quartz sand is said to occur near Fort Lockhart in the Kohat district, its locality being known to the Attock Oil Co., Ltd. However, efforts to obtain the position of this sand have been unsuccessful. It is probably one of the softer sandstones described by Davies in his monograph on the Samana Range.

Mardan district.

Quartz and felspar sand occurs in some of the dry river courses of the streams draining the outcrop of Buner granite in the Mardan district. This has been used with varying success for cutting marble at the Peshawar factory in which the Shahidmena (Khyber) marble was formerly prepared.

There are numerous outcrops of quartzite, which could be crushed and ground to provide an abrasive material, in the eastern part of the Mardan district.

Peshawar and Mardan districts.

Certain of the more arenaceous clays and slightly arenaceous limestones in the Peshawar and Mardan districts could possibly be used as fine abrasives for metal and other polishes. It is interesting to note that the abrasive agent in a certain well-known brand

of metal polish appears to be fine quartz, not exceeding 0·016 mm. in greatest diameter. Accordingly, it should be easy to crush some of the above rocks to this screening.

Alum and Aluminous Salts.

Khyber Agency.

Griesbach mentions the occurrence of lavender-coloured clay-shales, with beds of bituminous alum-shales, at several distinct horizons in his Metamorphic series, of possible Carboniferous age, in the hills near Shahid-mena (34° 9′ : 71° 17′), in the Mullagori country in the Khyber Agency; but no further details are available. I did not notice these during my short visits to the marble of this area.

When examining the tunnels along the Khyber Railway, Fox noted that the black and grey shales, which are occasionally crossed by zones of crush and shearing owing to the presence of finely disseminated pyrite, are subject to rapid alteration on exposure to damp air. The pyrite is decomposed and the sulphuric acid therefrom leads to the formation of alum, breaking down the shales into soft clay. The alum occurs as an efflorescence on the surface of the shales or in the tunnels which traverse these beds. After rain, the efflorescence is washed away; but in the following dry weather, more efflorescence appears.

Kohat district.

Wynne noted black alum-shales at Jatta (33° 19′ : 71° 17′) in the Kohat district and again in the rocky gorge near Bozha Banda in the same district. He states that the latter shales are evidently pyritous. There is little doubt that there are numerous similar occurrences in the district—the alum-shales of the adjoining Mianwali district were for long worked as a source of the alum they contained. Wynne mentions the appearances of once extensive sulphur or alum works on the right bank of the Indus near Dandi Hill station. These are situated on the road from Chorlakki to Dandi (33° 36′ : 71° 59′), about two miles from the former.

Antimony-ore.

Kurram Agency.

Agha Abbas mentions the existence of a mine of antimony in the Zalmukht hills, north of Thal (33° 22′ : 70° 35′) in the Kurram valley. The ore is said to be of inferior quality, but it was exported to Multan.

Arsenic-ore.

Chitral.

The ores of arsenic (orpiment and realgar) have been long known from the Chitral and the mines, judging from the size and extent of the workings, must be of some age. According to Tipper, the deposits are (1) Mirgasht Gol (11,000); (2) Aligot (13,000); (3) Londku (11,000); (4) Wizmich (16,000); (5) Moghono zom (15,000); and (6) Stach (14,000): the figures in brackets give the respective heights of the deposits. The first two lie on the northern side of the Tirich valley; the third is in the valley of the same name, the streams being a tributary of the Tirich. Wizmich can be reached by a difficult climb from Londku, but is preferably approached from the village of Washich in the Turikho. These four deposits lie on the same line of strike and the mode of occurrence is similar.

The Tirich valley is formed along a line of fault running N. E.-S. W. On the northern side of this fault occurs a large mass of altered limestones and calcareous shales. The limestones are mostly altered to marbles, but are in places still fossiliferous and contain well preserved Fusulinæ. These marbles from bold craggy peaks which are almost inaccessible and at Wizmich constitute the boundary between Chitral and Wakhan. Along the fault line, well exposed in the upper portion of the Tirich valley and continuing to the N. E., is a V-shaped body of basic intrusive rocks. On the south side, these abut on the shales and quartzites of the Sarikol series. The orpiment mines occur on the northern side close to the intrusive rocks and in the calcareous shales which are associated with the marbles. These shaly beds have been baked and altered by the intrusions.

After describing the deposits listed above, Tipper states that it is not easy to assess the value of the orpiment deposited. To put the older workings into order would be a long and probably expensive process and is only possible under the competent supervision of a trained mining engineer. It is doubtful whether the results that might be so obtained would be worth the expense entailed. The future success of the orpiment mines seems to lie in a discovery of untouched deposits by future prospecting. Tipper felt confident that there are other deposits awaiting discovery in the localities he mentioned.

Asbestos.

During his survey of the Shishi Kuh, the valley forming the geological continuation of the southern portion of the Chitral valley below Drosh, Tipper found large masses of basic igneous rocks in many places converted to serpentine. A white asbestiform mineral has been formed in veins and cracks in the serpentine. In spite of a very thorough search, no deposit of any size was found. Such asbestos as was noted was harsh, brittle and of poor quality.

Chitral.

I noted small veins of slip-fibre chrysolile asbestos in limestone near the junction with an intrusive epidiorite on the side of the road from Char Bagh Fort (34° 7′ : 71° 7′) in the Khyber Agency to the Kafir Kot Piquet post. The material was highly weathered and was of no economic value.

Khyber Agency.

Masson states that he procured specimens of asbestos from Kaniguram (32° 31′ : 69° 51′) in the Waziri country, but gives no further particulars. I could ascertain no knowledge of any deposits of asbestos whilst working in South Waziristan; but there is no reason why asbestos should not be found in the basic igneous complex of North and South Waziristan.

South Waziristan.

Building Stones and Road-Metal.

The chief building stone in the North-West Frontier Province is limestone or its altered product, marble. The marble of the Mullagori country in the Khyber Agency has been quarried for some years past and carted by motor lorry to a factory in Peshawar. From my various reports and papers in which I discuss this question, it will be seen that I have advocated the preparation of the marble at the quarry instead of in Peshawar, as by this means freight will be saved.

Marble.

The following descriptive notes concern chiefly the Shahidmena (34° 9′ : 71° 17′) marble, but will be equally applicable to some of the Kambela Khwar marble.

The marble is a pure, white saccharoidal stone, translucent in thin masses and equal in appearance to the Makrana marble of Jodhpur and Carrara marble. It has been worked successfully into translucent ornamental vases and vessels, plates, etc., of great

beauty. It has been used as an ornamental building stone (polished and unpolished) on a small scale in Peshawar for flooring, fire-places, etc. It has been used also for flooring with black slate from the quarries just over a mile south-west of Jhangira Road railway station (33° 57′ 30″: 72° 12′).

The Shahidmena white marble, sawn but not polished, costs about As. 11 per square foot in Peshawar; this may be compared with Makrana marble, also sawn and unpolished, which costs Re. 1 to Re. 1-1 per square foot in Peshawar.

After being roughly dressed at the quarries, the Shahidmena marble was carted by motor-lorry along the rough Mullagori road for about 26 miles to Peshawar, where it was sawn in a factory installed by the Director of Agriculture and Allied Departments near the goods railway siding. The blades used were of cold carbon steel, employing a cutting sand from a river-bed between Adina and Kalu Khan (34° 13′ : 72° 18′), near mile 15 on the Mardan-Swabi road. This sand contains a lot of felspar, which reduces its cutting power. The factory has since been sold to private interests; but the Government must be interested in the development of the marble industry along the right lines. In the past, very good quality white statuary marble from Shahidmena has been used purely as a building stone, instead of for ornamental statuary work for which it is admirably suited. When used purely as a building stone, it soon looses its white colour by the action of rain, dust and fumes in the atmosphere. There is abundant banded marble available at Lowaramena (34° 8′ : 71° 19′) in the Kambela Khwar, which would serve equally well as a building stone and could be used to avoid wasting the high-class statuary marble of Shahidmena.

Latterly attention has been given to the marketing of chips of white marble, which are being sold at 14 annas per maund f.o.r. Peshawar. These have to be between one-eighth and one-sixth of an inch in size. A market has also been found for marble dust, that passing through a sieve with a 144-mesh to the square inch being sold at Re. 1-5-0 per maund f.o.r. Peshawar.

Marble of good quality also occurs at Maneri (34° 8′ : 72° 28′) in the Swabi tahsil of the Mardan district. Green and yellow serpentinous marble of considerable beauty is also known to occur here, but not abundantly. These coloured varieties form very handsome stones which take a good polish. The white marble

of Maneri is of the same nature at the Shahidmena marble, being a pure, white, saccharoidal stone of handsome appearance.

In Table 3, I give analyses of certain marbles :—

TABLE 3.—*Analyses of marble from the Khyber, Mardan, Jodhpur and Italy.*

Rock number.	49/462	49/485	49/475	42/562	—
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	0·02	0·06	0·04	0·46	trace.
$Fe_2O_3+Al_2O_3$ . . .	0·10	0·18	0·05	0·04	0·11
CaO	54·60	54·40	55·86	56·08	55·64
MgO	1·61	0·88	0·33	0·90	0·41
Loss on ignition . .	43·86	43·69	42·58	43·28	44·17
P_2O_5	..	..	..	..	trace.
TOTALS .	100·19	99·21	98·86	100·76	100·33
Specific gravity .	2·72	2 70	2·71	2·73	..

49/462 White saccharoidal marble, lower quarry, Shahidmena, Mullagori country, Khyber Agency, North-West Frontier Province.

49/845 White saccharodal marble, 1½ miles W. S. W. Lowaramena, Kambela Khwar, Mullagori country, Khyber Agency, North-West Frontier Province.

49/475 White marble, Maneri, Swabi tahsil, Mardan district, North-West Frontier Province.

42/562 Marble, Makrana, Jodhpur State, Rajputana. Marble, Carrara, Italy.

Marble of good quality also occurs in the ridge known as Ghundai Tarako (34° 13′ : 72° 25′), which forms part of the boundary between the Swabi tahsil of the Mardan district and the Buner tract of Swat. After an exhaustive examination, I concluded that possibly the largest quantity of statuary marble in the Frontier Province will be found in the Ghundai Tarako.

The following are the results of the analyses of nine samples of the marble and dolomite of the Ghundai Tarako ridge, selected during a thorough inspection from south to north (Table 4) :—

TABLE 4.—*Analyses of limestone, marble and dolomite from Ghundai Tarako, Mardan and Swat.*

Rock number.	51/191	51/192	51/193	51/194	51/195	51/196	51/197	51/198	51/199
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	0·24	0·74	0·60	0·52	0·16	0·20	0·94	0·54	0·56
$Fe_2O_3 + Al_2O_3$ . . .	0·24	0·50	0·70	0·40	0·35	0·20	0·45	0·40	0·46
CaO	31·58	53·32	32·27	54·57	52·90	53·20	50·55	54·40	53·75
MgO	20·98	1·74	19·92	0·58	2·64	2·50	4·07	1·05	1·56
Loss on ignition . .	46·36	42·86	46·21	43·31	43·72	43·57	44·15	42·94	43·12
H_2O	0·18	0·32	0·25	0·23	0·27	0·33	0·13	0·34	0·20
S	..	..	..	0·02	..	..	..	..	..
TOTALS .	99·58	99·48	99·95	99·63	100·04	100·00	100·29	99·67	99·65
Specific gravity .	2·88	2·73	2·85	2·74	2·73	2·73	2·73	2·74	2·72

51/191 Grey-white dolomite, south-eastern end of Ghundai Tarako, Buner, Swat.
51/192 Banded grey recrystallised limestone, north of previous specimen, around spur, Buner, Swat.
51/193 Grey dolomite, south-western end of Ghundai Tarako, Swabi tahsil, Mardan district.
51/194 White saccharoidal marble, a quarter of a mile S. S. W. of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.
51/195 White saccharoidal marble, just south-west of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.
51/196 White marble, west of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.
51/197 White marble, a little north-west of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.
51/198 Greyish white marble, north-west of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.
51/199 Saccharoidal white marble, three furlongs N. N. W. of the main peak, Ghundai Tarako, Swabi tahsil, Mardan district.

It will be noted from a study of the figures in these tables that all the samples of limestone, marble and dolomite from Ghundai Tarako are of excellent quality; in no case does their silica content exceed one per cent. or their combined iron and alumina 0·75 per cent.

The Ghundai Tarako marble has been worked in the past by local *Khattacks* and taken by donkeys to neighbouring villages such as Nawe Kalai (34° 13′ : 72° 20′), Shekh Jana (34° 13′ : 72° 21′), Spinkani (34° 14′ : 72° 22′) and Shewa (34° 15′ : 72° 21′) to burn for lime. The cost of a *pari*, a heap of pieces of stone of about four cubic yards (six feet long by six feet wide by three feet high), delivered in Shekh Jana[1], which operation apparently takes one man about four days to complete, was quoted as Rs. 7. To Nawe Kalai, but a mile further, the cost was stated to be Rs. 10, as the operation takes six days. This indicates the primitiveness of the methods of extraction and transport so far used and it is obvious that the surface of the marble has only been scratched.

The main peak region seems to offer the best sites for quarrying. This area would have to be tested to see how far marble of good quality goes up the hill. It seems probable that nearer the summit, the marble is not so well recrystallised. The amount I saw of the Swat side of the ridge would seem to indicate that the best marble runs on the south-west, or Mardan, side.

According to the local workers, the largest-sized blocks of white marble that can be extracted would be about two to three feet in length. This is a disadvantage when the marble is quarried for statuary purposes, though not so important for minor building purposes; but it is highly possible that as quarrying proceeds along the dip into ridge and atmospheric agencies have had no opportunity to accentuate the jointing, much larger blocks will be available.

The Ghundai Tarako marble is relatively fine-grained. It is generally somewhat finer-grained than the Shahidmena and Kambela marble of the Khyber Agency and the Maneri marble from the Mardan district of the North-West Frontier Province, and much finer-grained than the Makran marble of Jodhpur. Approximately, it is equal in grain-size to the Carrara marble of Italy, and is more suitable for statuary, because it is easier to chisel than the coarser marbles; but fineness of grain would tend to make it less resistant to weather and therefore less suitable for exterior work.

[1] Sheikh Jana is only about 4½ miles west of Ghundai Tarako.

The Frontier Province is exceedingly rich in deposits of limestone of varying degrees of purity. Much of the limestone is burnt for lime, *e.g.*, at Nowshera, Ghundai Tarako, Maneri, Kohat, etc.

Limestone.

The following (Table 5) are previously unpublished analyses of specimens of limestome which I collected personally in the Bannu and Dera Ismail Khan districts and North and South Waziristan. They may be regarded as being typical of the limestone generally available in inexhaustible quantities in the North-West Frontier Province.

The acid volcanic rocks, which form the Karamar range east of Shahbazghari (34° 14′ : 72° 9′) in the Mardan tahsil of the Mardan district, offer abundant supplies of road-metal which could have extensive use on local roads. Mostly, however, softer limestones are used. Other rocks used as road-metal and building stone include epidiorites, quartzites, sandstone, shale, etc.

Road-metal.

The Attock slates in the Nowshera tahsil of the Peshawar district have been quarried in several places for use as a building stone. I visited the slate quarry in the hills one mile south-west of Jahangira Road railway station (33° 37′ : 72° 12′), where the Attock slates have a main cleavage dipping at between 75-80° to the N. N. E. Slates have extracted from here for use in various irrigation bungalows and for falls in canals for the past 20 years. They have also been used in flooring work in Government House, Peshawar, and other buildings in that city. The cost delivered in Peshawar was about As. 5 per square foot or Rs. 30 per 100 square feet. Blocks up to six feet by two were quarried. The slate replaces Chitorgarh slate in Peshawar, which costs about As. 9 per square foot. The slates at Jahangira Road will never have much economic importance. They will be useful for local building work, however, and there seems no reason why, when suitable, the local slate should not be used instead of the dearer Chitorgarh article. The cleavage planes of the Jahangira slate are not such as will facilitate the extraction of large blocks which may be easily split up into thin slates of even thickness.

Slates.

Other slate quarries exist about a quarter of a mile south-west of Chasmai (33° 57′ : 72° 8′), and near Manki (33° 56′ : 71° 58′), south of Nowshera, both providing a lighter-grey type of slate than the Jahangira quarry. All appear to be in the ancient Attock

TABLE 5.—*Analyses of limestones from the Bannu and Dera Ismail Khan districts and from Waziristan.*

Rock number.	K41/314	49/491	49/499	K41/315	K41/316	K41/317	49/500	49/501	49/457
Slide number.	24589	24590	—	24595	24591	24592	—	24593	24587
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2 etc.	0·26	1·70	27·20	3·52	3·26	4·64	3·50	1·20	3·16
Fe_2O_3, Al_2O_3	0·75	0·40	3·26	1·57	0·52	1·26	1·56	0·52	2·54
CaO	55·50	54·60	37·66	51·45	53·90	51·40	52·22	55·02	53·41
MgO	0·09	trace.	0·46	0·64	0·06	0·75	0·91	0·06	0·34
Loss on ignition	43·46	42·54	30·46	41·16	42·27	40·82	41·69	43·27	39·83
TOTALS	100·06	99·24	99·04	98·34	100·01	98·87	99·88	100·07	99·28
Specific gravity	2·66	2·70	2·71	2·72	2·66	2·71	2·72	2·69	2·71

NOTE :—All analyses, except that of 49/457 which was made by R. B. Ghosh, were made by Mahadeo Ram in the Laboratory of the Geological Survey of India.

K 41/314.—Jurassic limestone, slopes of Shekh Budin, two miles S. S. E. of Pezu (32° 19′ : 70° 44′), Bannu district.
49/491.—Takht limestone, 1¼ miles S. S. W. of Jamalzai (31° 28′ : 70° 3′), Shirani country, Dera Ismail Khan district.
49/499.—Belemnite limestone, one mile S. S. E. of Jamalzai (31° 28′ : 70° 3′), Shirani country, Dera Ismail Khan district.
K 41/315.—Dunghan limestone, half a mile west of Mughal Kot Post (31° 27′ : 70° 5′), Shirani country, Dera Ismail Khan district.
•K 41/316.—Limestone in the Isha grits, 1½ miles E. N. E. Isha Fort (32° 58′ : 70° 7′), North Waziristan.
K 41/317.—Coarse-grained limestone in Janjal Plant series, Bere Algad, east of Umarzai (32° 59′ : 69° 58′), North Waziristan.
49/500.—Fine-grained black limestone in Janjal Plant series, Bere Algad, east of Umarzai (32° 59′ : 69° 58′), North Waziristan.
49/501.—Zer Ghar limestone, west of Isha Fort (32° [illegible] : 70° 7′), North Waziristan.
49/457.—Limestone, 3,800-foot contour, 2¼ miles E. N. E. of Spli Toi Post (32° 20′ : 70° 0′), South Waziristan.

slates, the exposures of which in the Attock district have been described by Cotter. The slates do not extend as far west as Jallozai (33° 55′ : 71° 49′).

The following building materials are mentioned Middlemiss when discussing the geology of the Hazara district. The gneissose granite largely developed in the northern and western portions of the district splits readily into slabs and is used locally for building. Triassic limestone is quarried near Abbottabad (34° 9′ : 73° 16′) and Hasan Abdul (33° 50′ : 72° 45′), and furnishes a good durable stone, but somewhat sombre in colour. Limestone suitable for the making of lime is widely distributed, especially in the "Slate" and "Nummulitic zones". The harder courses among the Murree sandstones, found in the southern parts of the district, furnish an easily worked and fairly durable material. Some of the finely foliated schists are used for roofing purposes. Slabs of large size can be obtained, but are from half to one inch in thickness.

Hazara district.

Wynne and Waagen have suggested that the Attock slates might afford valuable roofing material.

The ægirine-arfvedsonite-granite, which crops out in the Mullagori country of the Khyber Agency, and forms Patigate Sar (34° 9′ : 71° 22′), would form a handsome building stone.

Khyber Agency.

Some of the more fissile varieties of the acid volcanic rocks forming the Karamar range in the Mardan district, referred to previously, are quarried for building purposes. The quartzites in the eastern part of the district could possibly be worked for building stone. The Buner granite, which crops out in that part of the district adjoining the Buner tract of Swat, generally cannot be suitably used as a building stone as usually it is not well jointed and it weathers rather easily.

Mardan district.

Chromite.

A specimen of chromite 1 collected from three-quarters of a mile E. S. E. of Pai Khel (32° 58′ : 69° 50′), near mile 54 on the Datta Khel road in North Waziristan showed doubtful chromite in thin flakes in the thin section. The occurrence is of interest as the serpentine is presumably of the same age as the extensive serpentines of Baluchistan, which contain

North Waziristan.

the richest chromite deposits in India. The surrounding country cannot at present be surveyed; but when, if ever, the tribes have settled to a peaceful existence, a further search in the area seems justified.

Cinnabar.

Chitral.

Cinnabar has been found by Tipper in the sands of rivers in Chitral. The occurrence is of great interest, but not of economic importance at the moment. However, the importance of the mineral merits a search being made, with great care, for the parent lode of sulphide minerals as a deposit of cinnabar would be of great economic value to the State.

Clays.

Bannu district.

Clay from the Shekh Budin *massif* was tested in the National Ceramic Testing Laboratory, Stoke on Trent, and a report stated that the clay fuses between 1580°C. and 1610°C. The report continued as follows:—

"This clay could be included in the plastic ball-clay type, except for its high percentage of iron. It is very remarkable that a clay with the percentage of iron shown by the analysis does not fire a red colour. It would be a useful clay to earthenware manufacturers who desired to use a clay to add to the ordinary earthenware body mixture to produce the ivory type of body, which is more popular at the present time than a white body. The clay gives a relatively high percentage residue on lawning through 120's, and it is fairly certain that some of the iron compounds in the clay are retained on the lawn."

Dera Ismail Khan district.

High up on the southern slopes of a westerly trending spur of Tumani Gundai, 1¼ miles S. S. E., of Paniala (32° 14′ : 70° 53′) occurs an argillaceous sandstone of variable hardness and composition which I examined. It is one of the beds of Jurassic series of this region. The National Ceramic Testing Laboratory stated that this 'siliceous clay' could be used for a third-grade fire-brick. The clay is reasonably clean and low in iron, and these are commercial advantages in a clay for fire-brick production. This clay was deformed at Cone 26-27, 1580°-1610°C.

On the northern slopes of the same spurs, I noted an unctuous clay which whitens on drying and exposure to air, and is distinctly more promising than the occurrence described above. Tests in

the Laboratory of the Geological Survey of India, showed that the clay did not fuse at 1400°C., but broke up on heating. This is, no doubt, due to the slight gypseous content. I made recommendations for trial pits and sampling for the possible development of this clay, but nothing further seems to have been done.

Hazara district.

According to Middlemiss, clays occur in the Kagan (34° 47′ : 73° 31′) and Konsh valley, which were tested in the Laboratory of the Geological Survey of India and found to be suitable for use as china-clay.

Khyber Agency.

I inspected a clay high up on the Besai ridge north of the Khajuri plain, which was formerly mined and sold to the pottery makers in Peshawar at about Re. 1 per bag as an ingredient for their glaze. The following is the result of a test made on this clay on the Laboratory of the Geological Survey of India :—

	Unwashed clay.	Levigated sample.
Colour unburnt	Cream	Light cream.
Colour burnt	Lavender grey	Lavender grey.
Plasticity	Poor	Moderate.
Shrinkage	About 25 per cent. by volume.	About 25 per cent. by volume.
Refractoriness	Does not fuse at 1400°C., but becomes porcellanous.	Does not fuse at 1400°C., but becomes porcellanous. Its appearance at this temperature suggests that it is approaching fusion point, and it is doubtful whether it would be suitable as a fire-clay.
Remarks	Very gritty and somewhat ferruginous. Unsuitable as a fire-clay, china-clay or filler. May be useful for glazed pipe ware.	May have some use as a filler where colour is no detriment. Would be unsuitable for electric insulators. It may have some use for glazed pipe ware.

Kohat district.

A sample of clay found in the Kohat district was forwarded to the Geological Survey of India in April, 1937, by the Director of Agriculture, North-West Frontier Province, in order to obtain an opinion as to the suitability of the clay for the manufacture of porcelain insulators and fire-bricks. The clay was light grey in colour and had good plasticity. However, it decrepitated on heating and had no value for the manufacture of insulators. It could be used as a cloth and paper filler.

According to a report dated the 19th June, 1935, by the National Ceramic Testing Laboratory, North Staffs, Technical College, Stoke-on-Trent, England, on a sample of clay from Jahangira (33° 58′: 72° 13′ 30″) in the Swabi tahsil of the Mardan district.

Mardan district.

"This clay is fairly plastic and will vitrify at Cone 8. It is remarkable, almost unique in its high content of steatite, probably accompanied by Dolomite. This clay is the only one of the three that is of possible use in manufacturing electrical insulators, but suffers from the objections that the fired colour is poor owing to the iron content, and also that the glazed article would have a tendency to craze, owing to the low silica content. This crazing tendency would be prevented to a large extent by the steatite present, and if the fired colour is not a serious objection, the clay might be worth a trial fired to Cone 8."

This clay was analysed by the National Ceramic Testing Laboratory with the following results:—

	Per cent.
SiO_2	39·05
TiO_2	0·43
Al_2O_3	13·97
Fe_2O_3	3·44
MgO	21·34
CaO	5·64
K_2O	0·04
Na_2O	0·06
SO_3	2·78
Loss when calcined at 950° C	13·00
Total	99·85

The analysis was made on the dried sample of the clay after the hygroscopic moisture had been lost at 110°C.

In 1936, I was shown a clay a quarter of a mile north-east of the eastern end of the bridge of boats across the Kabul river at Jahangira on the left side of the river, just above its junction with the Indus river. This clay appeared to be part of a terrace of horizontally bedded river and ? glacial deposits formed, no doubt, when the Indus and Kabul rivers were dammed in the vicinity of Attock. This argillaceous material is of a vavre nature and is interstratified with beds containing gneissic and granitic pebbles of the same nature as those found lying on the Attock slates on the right side or the Kabul and Indus rivers. It is greenish and pinkish in colour and is at times sufficiently pure to be quarried and used as *Multani*

matti. It is marketed in Rawalpindi and other places for use on the white boards the local school-children use as slates. After being mixed into a paste with water, and spread on the wooden 'slates', the latter are placed in the sun to dry. School-children write on the 'slates' with ink, which is absorbed quite well. The clay or shale is also eaten by pregnant women.

Certainly this is not the same material as that sent to the National Ceramic Laboratory, nor do I think such steatitic material exists near Jahangira east of the Kabul river. Elsewhere in this paper, however (see pp. 46-47), I have described certain occurrences of steatite south-west of the Kabul river.

Peshawar district.

An analysis of a Peshawar clay is included in the files of the Geological Survey of India. The locality where this clay was obtained is not given, but the clay was possibly a levigated sample of the clay from north of the Kajuri plain, which was purchased in the Peshawar bazar. It is said to burn light brown, to be a good fire-clay, and to have a possible use in ceramics.

South Waziristan.

A white rock, or clay, appears to occur in the hills between Kutmar Sar and Pre Ghal in South Waziristan. Specimens of country-rock of the region brought to me by *Khassadars* were biotite-granite; and so there is a possibility that the white material, which shows up well from a distance, may be kaolin formed as a decomposition product of the felspars of the granite.

General notes.

Poor-grade clays are, of course, used locally by the indigenous potter and in the manufacture of bricks. No figures of the amount and value so utilised are available. There seems little doubt, however, that an intensive search would result in the discovery of better-grade clays; but whether these would be favourably situated for economic development is doubtful.

Coal.

Hazara district.

I do not think that the coal of the Dore river in the Hazara district will be of economic importance. In my relevant report, I have stated that there is no continuity of outcrop owing to numerous faults and earth movements; the quality of the coal is very variable and usually poor; the thickness of the seam is either variable or small, or has

a false appearance of value imparted to it by the presence of carbonaceous material which is little more than shale; and finally, the coal-bearing sandstone is either so kneaded up and crushed by earth movements, owing to its position between two hard limestones which have acted as crushers, as to be usually impossible of being worked commercially.

The possible economic value of the Dore river coal deposits has been a point of interest to those concerned for a long time. A short history on the investigations is given in the "Coal" section of the Economic Geology Appendix to C. S. Middlemiss' memoir on the geology of Hazara and the Black Mountain. Middlemiss' notes contain analyses and supplement the preliminary report that he had submitted previously, which was accompanied by a sketch section showing the geological structure of the area.

The chief earlier report was that by D. Morris, who was Executive Engineer in charge of Coal Mines, North-Western Railway. Morris stated that as early as 1883, it was found that the "shale" should be utilised in lime- and brick-burning.

One of the chief points of interest is the variation in the quality of the different specimens of the coal that were analysed. An anthracitic sample sent by Morris to the Geological Survey of India showed a fixed carbon percentage of 86·26 and an ash percentage of only 3·92. The first two samples sent by Captain Abbot to Calcutta for analysis showed ash percentages of 18·75 and 21·75, with moisture percentages of 17·78 and 1·90 respectively. However, a representative series of samples from near Jaswal (34° 6′ : 73° 16′), obtained by Middlemiss and Hira Lal, showed an average ash percentage in the first nine feet of 46·03; at the tenth foot, the ash percentage was 17·20; but below this, the average ash percentage was 31·95.

Morris's report refers to the trial heading driven by the Public Works Department in 1888 that was abandoned later owing to an influx of rain-water. This is situated about 1¼ miles E. N. E. of Dhamtaur (34° 8′ : 73° 16′), on the left hand (south-east) side of the Dore river. About 1,000 maunds were extracted from this working, of which 800 maunds were sent to Hasan Abdul for trial as a locomotive fuel. The other old mine, known as Hewson's mine from the name of the clerk in the Deputy Commissioner's office in Hazara who prospected for coal and spent much time and money in the enterprise when on furlough, is on the right-hand

(north-west) side of the Dore river, about 1¼ miles north-east of Dhamtaur. About 6,000 maunds of coal were extracted from Hewson's mine and used in Abbottabad for lime- and brick-burning after being made into slop-moulded bricks.

Up to the time of the writing of Middlemiss' 1896 report, apparently the P. W. D. and Hewson's mines were the only trial efforts made to prove the Dore river coal. They were not successful.

The chief point of interest is the exact horizon of the sandstone with which the coal is associated. In my report on "The Relation of the Coal of the Surghar Range to the Boundary between the Kohat District of the North-West Frontier Province and the Mianwali District of the Punjab", following Gee, I have placed the Makarwal coal stage as Lower Ranikot (basal Eocene). Middlemiss is correct in regarding the grey limestone of the Dore river and Hazara as Eocene, making the coal stage higher than Lower Ranikot. His chief reason for this was apparently convenience for field mapping, for he states:—

> "A series of well-bedded grey limestones with, so far as I have seen, a complete absence of fossils, except extremely minute organisms, probably foraminifera, overlies this M. Cretaceous band. Waagen and Wynne considered it possible that it might also be Cretaceous, but gave no definite reasons. In the absence of proof I have preferred to place the grey limestone with the Tertiaries as the lowest bed of the Nummulitic series, more especially as, for reasons stated under the next heading, it is not everywhere easy to draw a line between the Grey and Nummulitic limestones, whereas the top of the orange Middle Cretaceous band is everywhere a marked feature easily seized for mapping purposes."

However, my specimens of the grey limestone show abundant small forams and so there is no doubt that the Dore river coal stage is higher than Lower Ranikot, and so is not homotaxial with the Makarwal coal stage. It is interesting to note, nevertheless, that Middlemiss states that he has little doubt that the Dore river coal is homotaxial with the coal of the Salt Range "which is also found at the base of the Nummulitic limestone". He also states that the sandstone accompanying the coal is underlain by a coarsely pisolitic ferruginous band and in the event of the grey limestone being Cretaceous, this band

> "would very reasonably represent the similar rock at the base of the Nummulitic series at Sabathu and in western British Garhwal".

It would appear that the only known occurrence in the North-West Frontier Province of coal of possible economic importance is in the

Kohat district, just north of the Baroch gorge, and near its junction with the Mianwali district of the Punjab. I recommended that it was extremely desirable that this coal should be proved; and stated that if proved, it could be worked by drifts from the Frontier Province side and transported by aerial ropeway to the Punjab side of the ridge. I understand that this potential coal area has been included in a mining lease granted, presumably by the Local Government, to the Makarwal Coal Co.

Kohat district.

The outcrops of the coal in the neighbouring parts of the Punjab will be further delineated by the Geological Survey of India in the 1939-40 field season. The results of this field work will have some interest to the Government of the Frontier Province, as well as to that of the Punjab.

According to Gee, the Makarwal coal stage is Lower Ranikot or basal Tertiary in age. The stratigraphical sequence is as follows:—

11. Alluvium.
10. Upper and Middle Siwaliks (Upper Tertiary).
9. Lower Siwaliks (Miocene)
8. Upper limestones (Laki)
7. Olive shale stage (? Ranikot)
6. Lower limestone stage (Ranikot)
5. *Makarwal coal stage* (Ranikot)

   (8–5: Eocene).
4. Massive sandstone stage (? Cretaceous).
3. Belemnite shales (Upper Jurassic-Lower Cretaceous).
2. Upper Jurassic limestones.
1. Variegated stage (Jurassic).

From the field evidence, there seems little doubt that a dark red, pisolitic, haematite shale, or so-called laterite horizon, is sometimes developed at the expense of the coal, and there is a slightly irregular junction then between the sandstones of the basal Eocene Makarwal coal stage and the Cretaceous sandstones.

There is thus evidence of a 'break' between the Cretaceous and the overlying strata.

According to Gee, the main Makarwal seam varies up to 12 feet thickness, but is usually from four to eight feet thick. It occurs at the base of the Makarwal coal stage; and half-way up the 130 feet of "bedded grey and variegated, fairly massive sandstones alternating with ochreous, grey sandy shales with imperfect plants" is a

second, "Thinner seam of coal and shaly coal about 1 to 1½ feet thick at the outcrop". It is only the lower, basal seam that is worked.

A number of analyses of the seam are given by R. R. Simpson in his paper "Report on the Coal Deposits of Isa Khel, Mianwali, Punjab", and Gee discusses its quality in the economic section of his report, to which reference should be made. In addition, the following are the results of the analyses by Mahadeo Ram in the Laboratory of the Geological Survey of India of samples of coal from the Lamshiwal and Simpson groups of mines collected by Gee and myself from trucks at the Makarwal Colliery siding. These may be considered as typical of the coal despatched from the Colliery.

	Lamshiwal group.	Simpson group.
	Per cent.	Per cent.
Moisture	2·80	3·04
Volatile matter	42·34	43·43
Fixed carbon	36·94	44·29
Ash	17·92	9·24
	100·00	100·00
Specific gravity	1·44	1·34
Ash	Drab.	Drab.
Caking quality	Cakes strongly.	Cakes strongly.
Sulphur percentage	6·35	5·90

The general geological structure of the Surghar range is that of a fold-faulted anticline, the axis of which runs north and south to the east of the crest of the range. Generally the eastern limb of the anticline is either so faulted or has been so eroded away that little coal can be extracted. The western limb forms the main ridge and the coal seam dips at fair angles into the range. The anticline pitches south beyond Lamshiwal towards the Mitha Khatak gorge.

On page 21 of his paper, Simpson mentions two seams, the upper one nine inches and the lower one three feet thick, occurring in the supra-Jurassic sandstones (Makarwal coal stage). He notes that the lower seam is

"of fairly good quality. Its outcrop crosses the Barochi stream at a point about 2 miles west of, and 300 feet above, Malla Khel. The dip at this point is to the

west at an angle of 45°. Traced northwards from the ravine the seam rapidly thins to 9 inches, and becomes more stony and pyritous. Two miles further north, near Shaikh Nikka summit (3,990 feet), the supra-Jurassic sandstone is found crowning the range. The band of coaly shales is present but the coal is frequently absent and never exceeds 8 inches in thickness."

Plate 2 of Simpson's paper is a misleading and incorrect map. It shows the Baroch *nala* as rising in the Baroch gorge and cut off totally by a ridge from the Maidan Baroch and Khora Baroch streams. It also shows the coal seams as cropping out entirely within the Punjab; but his boundary line differs from that now shown on the latest one-inch map (See sheet 38 P/1).

It will be seen that the coal seam does in fact crop out in the North-West Frontier Province by the "H" of "SURGHAR" in the Baroch gorge and to the west of point 2,997 feet. The prominent peak 3,987 feet still further north is undoubtedly the hill "Shaikh Nikka" referred to by Simpson. Simpson's sample of coal No. 5 is thus undoubtedly coal in the North-West Frontier Province. He notes 2 feet 1 inch of coal and 10 inches of coaly shale and his analysis of a sample from the coal band was as follows:—

	Per cent.
Moisture	5·20
Volatile matter	33·26
Fixed carbon	36·27
Ash	16·00
Sulphur	9·27
TOTAL	100·00
Ash	Brown.
Caking quality	Cakes poorly.

This coal would be of good quality apart from its sulphur content. Unfortunately a deep pool in the Baroch prevented Gee and myself from following up the gorge to the place from where the sample was taken; nor could we drop down to the seam from above on account of the sandstone cliffs, so that the coal was not examined.

Simpson has stated that the seam rapidly thins to nine inches as it is traced northwards; and that towards Shaikh Nikka, the coal is frequently absent and never exceeds eight inches in thickness. However, it certainly seems worthwhile thoroughly testing and proving the area between the Baroch and Shaikh Nikka; and to enable this to be done, every encouragement should be given to mining companies and prospectors. The total cost of proving the area

from the Baroch gorge northwards to just beyond the point 2,997 feet, which is the most promising area, should not exceed Rs. 2,000—3,000.

South Waziristan.

A small amount of lignitic coal occurs one mile east of Mira Kwand (32° 21′ : 69° 58′) in the Spli Toi in South Waziristan in the carbonaceous shales which are part of the Nai Kach stage of the Spli Toi (Upper Cretaceous) series. Picked pieces of bright coal which I collected gave a very small percentage of ash (0·66), but the occurrence has merely scientific interest.

Agha Abbas mentions an occurrence of coal beyond the Pir Karal, a hill to the north-west of Kaniguram (32° 31′ : 69° 51′); apparently no details are given.

Copper-ore.

Chitral.

In 1921, Tipper had noted the presence of traces of copper as incrustations on cracks in the granite of Mirkanni at the foot of the Laorai pass in Chitral. In 1922, he found that this granite extends on both sides of the Chitral river into Afghan territory on the south-west. Associated with this granite are basic rocks as dykes and segregation patches. The latter rocks are often serpentinised, and when they occur as segregation patches, the granite in the neighbourhood contains copper pyrites, often decomposed to carbonates.

North Waziristan.

When at Datta Khel Fort in North Waziristan, I was given a specimen of impure cuprite, with malachite, that was said to have been obtained from the Spinchilla Narai (32° 55′ : 69° 49′), a few miles east of the Fort. The locality indicated the existence of the possibly Tertiary basic igneous complex which I followed eastward over the Lwargi Narai. Details of the occurrence are wanting; but it is interesting to recall that specimens of calcite and chalcopyrite, with malachite staining, from the Shawal region, Upper Tochi, were sent to the Geological Survey of India in 1928 for identification.

Dolomite.

Kurram, Agency.

A boulder of white crystalline dolomite, found in the Zeran Tangi, a few miles east of Parachinar (33° 54′ : 70° 6′) in the Kurram Agency was forwarded to me by the Director of Agriculture in the North-West Frontier

Province. The Zeran Tangi here does not have a very large watershed, and there seems little doubt that the dolomite forms part of the ? Devonian limestone series noticed by Cotter in 1926. An analysis of the rock showed 20·42 per cent. magnesia.

Mardan district and Swat.

Some of the specimens of white and grey marble, which I collected from the southern end of the hill Ghundai Tarako, which forms part of the boundary between the Mardan district of the Frontier Province and Buner tract of Swat proved, on analysis, to be dolomites (see p. 18). The extent of the occurrence of dolomite amongst the marbles of this ridge can only be gauged by extensive sampling in the field. It is possible, however, that a little search will indicate the existence of bands of relatively pure dolomite in commercial quantity.

Fluorite.

Chitral.

Fluorite was found by Tipper to be associated with realgar and orpiment at Mirgasht Gol in the Tirich valley in Chitral. The deposit has mineralogical interest.

Gold.

Reef-gold.

No occurrences in commercial quantity of gold in reefs in the North-West Frontier Province are known.

Hazara district.

When I was at Abbottabad in April, 1937, I was informed that gold occurs in the reefs near Tarbela (34° 7′ : 72° 49′) on the Indus river in the Hazara district. I prefer to disbelieve this until I have seen actual specimens; but it would appear that a search could be made in this locality for auriferous reefs.

Khyber Agency.

Gold also occurs in small quantity in a pyritous mineral associated with a mineralised limestone near Char Bagh Fort (34° 7′ : 71° 7′) in the Khyber Agency; but the occurrence is in such small amount that it likewise has merely mineralogical interest.

Mardan district.

Gold definitely occurs in certain of the acid volcanic rocks north of Injan Dheri (34° 14′ : 72° 17′) in the Mardan district, but in very small quantity. The quantity is less than 0·3 grains per ton and so the occurrence has

merely mineralogical interest; but is interesting in suggesting a possible source of some of the alluvial gold of the Kabul river and its tributary, the Kalpani *nala*, which has been washed in the past.

Alluvial gold.

The following occurrences of alluvial gold have been listed in my paper on gold in the North-West Frontier Province.

Chitral.

In Chitral, gold-washing has been carried on from time immemorial, but it has been neglected during the last few years. Gold-washing is a State monopoly, and the workers perform their task in return for the small estate they enjoy, never exerting themselves to a great extent. No further cess or toll is levied on the gold. During the summer months, the Chitral river is in flood, covering all the sands on either side; and in the winter months, the water is too cold to allow work to be done. The result is that the working months for gold-washing are only from the middle of September to the end of November in autumn, and from the middle of March to the end of May in spring, *i.e.*, a period of about five months annually. The only tributaries of the Chitral river which carry gold are the Reshun Gol, Kuragh Gol and Roman Gol, all of which rise in the Phargam mountain. This area was visited by Tipper who traversed the Golen river and descended by the Reshun Gol to the Yarkhun (Chitral) river. He mapped the Phargam mountain as "granite, gneiss, etc.", and states that the typical Mirkhanni granite passes laterally through diorite into a doleritic trap rock. It would appear that the gold in the Phargam mountain which is responsible for the gold in the three named tributaries in the Yarkhun river, is in disseminated state through the igneous rocks forming the Phargam mountain complex; and it is extremely unlikely that one will be able to spot the source of the gold, or that the Chitral gold will ever be worked except when nature has concentrated it in river gravels.

Hazara district.

According to C. S. Middlemiss, gold is washed from the gravels of the Indus river above Lalogali (34° 16′ : 72° 50′), near Kirpalian (34° 17′ : 72° 51′). It is interesting to note that in his classic book on gold, Maclaren states that above Attock, and in the upper waters of the Indus, and in the Alakananda, are small gravel banks that were even then (1908) worked. Much of this gold, he states, is probably derived from the Tibetan plateau, since many of the Indo-Gangetic streams

have pushed their way through the main range and captured some of the drainage channels of that region.

Some of the *belas* or islands in the Indus, which are worked from time to time by the indigenous gold-washers, are partly in the Hazara district and partly in the Mardan district.

Kohat district.

According to A. B. Wynne, gold-washing is carried on during the rains in the Teri Toi near Banda Zartangi village (33° 17′ : 71° 32′), the practice being responsible for the name of the village. The source of the gold is unknown, but I suggest that one or more of the conglomerates in the Siwaliks drained by the Teri Toi in some of its upper reaches is auriferous. Wynne also states that stream gold is washed in the Indus and that platinum is reported to occur with it. He adds that gold is washed for in the Kurram river.

Mardan district.

In my paper on gold in the North-West Frontier Province, I gave details of Colonel Noel's experiments with the gravels of the Indus in the Mardan district. From these and later experiments we conducted together in April, 1939, it does not appear that the gravels of the Indus between Tarbela and the Attock gorge are likely to contain alluvial gold in sufficient quantity to be worked on a commercial scale. At present the gravels are worked sporadically by the indigenous gold washers in a primitive fashion. If sluices were used, the yield would be much greater, but even then the deposits are not rich enough to work extensively.

The gravel is collected in wooden bowls called *pallais*. Each bowl holds about half a cubic foot of gravel.[1] Thirty *pallais* are taken to the *nawa*, a wooden tray 3 feet 6 inches long, 1 foot 10 inches wide, inclined at 1 in 8, where the bigger stones are screened. Small stones about the size of an orange are placed at the lower end of the *nawa* to prevent the sand being washed out. The smaller sand falls on to the *nawa* and when this is full, the sand is washed until about a cupful remains. This is mixed with mercury equal to a small pea in size. The sand is again washed until the pellet of mercury is left; but when there is still about a table spoonful of sand left, the mercury and sand are well amalgamated. The pellet of mercury is then wrapped up in a piece of cloth and about

[1] Actually the results given in this and the succeeding paragraph require some modification. When Colonel Noel and I conducted our experiments in April, 1939, we found that the gold-washers more usually placed about one-fifth of a cubic foot, and not one-half of a cubic foot, of sand and gravel in each *pallai* they took.

half the mercury is squeezed out. The remainder, with the cloth, is then burnet on a few live embrs. The gold emerges as a nodule.

About thirty *pallais*, equal to 15 cubic feet of gravel, were washed, giving three-quarters of a *ratah* of gold.[1] Four to five *navas* are washed in a day, *i.e.*, approximately 67 cubic feet of sand and gravel. At the time of Colonel Noel's experiments, a *ratah* of gold was worth about Rs. 0-5-0[2], and so, taking the day's workings of the gang as about six *ratahs*, the value of the gold won daily was Re. 1-14-0. If the yield fell to one *ratah* per diem, then work was abandoned as being unproductive. The highest yield obtained from a day's working was four *mashas*, or 32 *ratahs*.

Gold-washing is carried out occasionally in the Kalpani *nala* south of Mardan (34° 12′ : 72° 2′). I have referred above the possible source of that gold.

Perhaps the most interesting results of Colonel Noel's earlier experiments were that certain of the gravels of the dry tributaries of the Indus river below Attock contained a larger quantity of gold than the gravels of the Indus itself. Colonel Noel sent a sample of sand and gravel from the dry ravines leading to the Indus river some three miles below Attock to the Geological Survey of India, Calcutta, for examination and report. This proved to contain 18·8 grains of gold per cubic yard. This averages less than 2 dwts. per 3 tons of alluvium, whereas it at present only pays to work 2 dwts. per ton of alluvial ground on a large scale. It seems possible that these ravines below the Attock bridge may be worth prospecting thoroughly.

Peshawar district.

It would appear that the sample from the dry tributaries which was sent to the Geological Survey of India in Calcutta was obtained from near Darwazai (33° 50′ : 72° 14′). It is understood that the Indus river has never been near the site of the gold-washing experiments in these dry ravines, and so it is impossible for the auriferous sand and gravel to have been derived from the Indus river in its wanderings. Accordingly, it would appear that these sands and gravels have been derived from the denudation of the Attock shales and slates which continue across the Indus from the Attock side, where they have been described by G. de P. Cotter, who remarked that quartz veins are very common in these rocks. I noted the frequency

[1] 8 *ratahs* = 1 *masha*; 12 *mashas* = 1 *tola*; 96 *ratahs* or 1 *tola* = 180 grains; 1 *ratah* = 1·875 grains; 24 grains = 1 dwt.; 20 dwts. = 1 oz.

[2] The market price for Indus gold was Rs. 30 per *tola* or Rs. 80 per oz. (Troy).

of quartz veins when examining the steatite deposits along a fault-line in the Attock slates near Kund (33° 56′ : 72° 14′). It would appear, therefore, that some of the quartz-reefs in the Attock slates in the hills west of the Indus below the Attock bridge may be slightly auriferous.

It may also be noted here that gold-washing is occasionally carried out in the Kabul (Landai) river near Nowshera (34° 0′ : 72° 0′), near the junction with the Kalpani *nala*. The source of this gold may be the very slightly auriferous, acid volcanic rocks referred to previously.

Swat and Gilgit. According to H. G. Raverty, quantities of gold dust are collected in Bajaur and Swat:

'They adopt another mode than washing the sands of the river, by half burying sheep-skins in the beds of the streams, allowing the wool free play and in this the particles of gold become entangled. I am told by the Afghans of these parts that the gold thus obtained is of a much paler yellow than that seen in the Punjab and in India, being almost straw colour.

In the Gilgit valley, and that of Hunzi, and Nagyr, which open into it from the north-east, and also in Little Thibet, the ore is principally obtained by washing.'

Elsewhere he says that no gold is found in the Swat river or its smaller tributaries, unless it be at their sources.

Graphite.

In his account of the geology of the Khyber hills, Griesbach has noted a metamorphic series, of possible Carboniferous age, which contains graphitic layers. The metamorphic series occurs north of the Tor Sapper.

Khyber Agency.

He states that lavender-coloured clay-shales, with beds of bituminous alum-shales, form several distinct horizons, which contain numerous layers of graphite and graphitic shales. From my inspection of these near Shahidmena (34° 9′ : 71° 17′) and east of Lowaramena in the Mullagori country, the occurrences do not appear to have any economic value.

Gypsum.

Dera Ismail Khan district.

A zone composed of alternating bands of dolomite and gypsum, from 450 to 500 feet in thickness, was noted by Wynne in a cliff section near Saiduwali (32° 12′ : 71° 6′), at the southern end of the Khasor range.

Plates of selenite also occur in the Jurassic clays exposed on the southern scarp of the Sheikh Budin hills near Paniala (32° 15′ : 70° 56′); and at the base of the same scarp an exposure of the 'salt marl' was observed by Verchère, with some massive beds of gypsum.

A band of gypsiferous shales, alternating with beds of limestone, occurring at the base of the upper Nummulitic group, was traced by La Touche from the Toi river in the south of the Shirani country to the Zao defile in the north, a distance of 24 miles. In a measured section at Zor Shahr (31° 42′ : 70° 8′), about the centre of the band, 12 beds of gypsum were counted, varying in thickness from a foot to 11 feet 7 inches, with an aggregate thickness of 50 feet. Nodules of gypsum also occur in the associated limestones. From my own inspection of sections in the Shirani country, I am on the opinion that the reserves of gypsum here are large.

Hazara district.

The occurrence of gypsum, forming beds or veins in the slate series, has been recorded by Middlemiss. An isolated small exposure was noted at Dowatta (34° 17′ : 73° 30′), and the discontinuous outcrop of a bed or vein between the villages of Bijora and Bari-ka-Bugla, passing along the east slope of the hill marked 6,462 feet (34° 10′ : 73° 30′), where it reaches a thickness of 100 feet.

Kohat district.

An important development of gypseous beds in the upper portion of the Eocene nummulitic series has been described by Wynne. The beds are exposed in all the ridges extending from the neighbourhood of Bahadur Khel (33° 11′ : 71° 1′) eastwards to the Indus, covering an area of about 50 miles in length by 20 miles in maximum breadth. The gypsum occurs in discontinuous masses, which occasionally attain a thickness of at least 200 feet, and is associated with bands of clay, and in the lower portion with black shales strongly impregnated with petroleum. The colour is usually white or grey, but sometimes deep red, owing to the presence of iron.

Thick beds of massive white and light grey gypsum overlie the salt-bearing marl. According to Gee, the quantity available is, from a commercial standpoint, unlimited. He adds that minor quantities are also associated with the Upper Nummulitics, though a massive outcrop occurs near Panoba (33° 37′ : 71° 54′).

Gypsum is used for the manufacture of plaster of Paris, stucco, and various kinds of wall plasters and cements. In the tin plate

industry, gypsum is used for polishing the plates; and it is added to water to give permanent hardness in brewing. The coarser grades of gypsum are used as fertilisers. At present the Frontier Province's resources of gypsum are untouched; and it seems that attention could profitably be directed to the utilisation of this potential economic mineral which occurs in abundance in the Dera Ismail Khan and Kohat districts.

General notes.

Iron-ore.

Bajaur.

Raverty and Oliver mention the occurrence of iron-ores in large quantities in the valley of the Panjkora river, especially, in Baraul and in the Laspur Jandawal hills. The iron is exported to Kabul, where it is said to be greatly esteemed. The ore is believed to be magnetic iron sand.

Bannu district.

Iron-ore is said to occur in abundance among the hills to the south-east of Bannu (33° 0′ : 70° 40′). The metal is worked up at Kalabagh into nails, cooking utensils, etc. The ore appears to be an earthy hematite.

Chitral.

Tipper noted abundant hematite in the quartzites of the Chitral slate series, half-way between Sanoghar and Mastey on the bank of the river, the talus slopes here consisting of hematite-quartzites. Without fuel and at such a distance from any large centre, the iron-ores can have little value except in so far as they may be of local use.

Hazara district.

A band of earthy, concretionary or pisolitic hematite, associated with felsitic breccia, was observed by Middlemiss on the north-east spur of Sirban Hill (34° 7′ : 73° 16′). In places the band consists of good earthy hematite, five to six feet in thickness, which would be useful as an ore if fuel were available.

North Waziristan.

Smith noted the occurrence of concretions of very pure soft hematite in Middle or Lower Eocene sandstone beds at Miran Shah in the Tochi valley in North Waziristan. The quantity available is said to be sufficient only for local needs.

South Waziristan.

I noted beds of slightly manganiferous limonitic iron-ore near Malik Shahi, west of Kotkai (32° 24′ : 70° 2′) in South Waziristan, in what are probably Laki shales. The amount is indefinite, the ore is poor and there is no good fuel nearby to work this ore.

I also noted abundant ferruginous concretions near Mangora Sar and Bobalai, east of Ladha Camp, in the Mangora Sar shales of the Janjal Plant series. The indigenous iron-workers of Kaniguram (32° 31′ : 69° 51′) and Makin have possibly used these concretions, together with the Kotkai limonite, as the source of some of their iron-ore; but the concretions also have no commercial value.

The manufacture of iron at Kaniguram has been described by Agha Abbas and Verchère. The latter observer states that the ore is a highly ferruginous shale, occurring beneath nummulitic limestone, and that apparently limestone is used as a flux, though the actual operation of smelting was not witnessed. Specimens of the ore collected by Stewart proved to be calcareous limonite, containing from 31·8 to 40·4 per cent. of metal.

Lead-ore.

Chitral.

Tipper noted a deposit of jamesonite, a sulphantimonite of lead, five miles south of Awi in quartzite abutting on a high ridge of white crystalline limestones, which are strongly siliceous and partly dolomitic. Attempts have been made to utilise the mineral locally as a source of lead, but without any great success. Unfortunately, unless there is a considerable percentage of silver in the ore, jamesonite is not used as a source of antimony.

Galena, the sulphide of lead, is rarely found alone in Chitral, being usually accompanied by blend, pyrites, jamesonite, etc. Tipper noted galena at the following localities: the ridge between Shot and Shagram; the ridge between Dhoni and Gokshal, up the Chitral Gol; 1½ miles up the Galuret Gol; near Yakdey; and near Andraguach. With the exception of the first, these deposits are small and irregular, the galena occurring at patches or scattered crystals in quartz or other minerals. The deposit between Shot and Shagram has been mined; but many of the old pits are now obscured. The vein, which carries pure galena, runs parallel to the strike of the shales and has a dip corresponding to that of the shales. This dip is high,. 57° to the S. S. E. The excavation shows that the vein is variable in thickness from 2 inches to 18 inches, the mineral occurring in a soft calcareous clayey matrix which is easily excavated. The pit seen had been carried down to a depth of 60 feet on the dip. The amount of material available is so small that it can only have local value.

Zinckenite, another lead sulphantimonite, has recently been mined and exported from Chitral (see Table 2, p. 11). The mineral is supposed to occur at Shaghor and the mining lease is held by a Mr. Parekh. No further details of the occurrence are available.

Manganese-ore.

Chitral.

Tipper in 1921 noted in basic patches occurring as segregations and dykes in the Mirkhanni granite in Chitral, near the village of Damel, masses of a soft black mineral which proved on examination to be manganese-ore.

Kohat district.

A bed of flattened concretionary nodules, consisting of limestone impregnated and partly replaced by manganese oxide, was found in 1906 by Amin Khan, a student at the Cawnpore Agricultural College, on the western slopes of Tajut Hill (Taghoot Sir; 33° 31′ : 71° 12′), two miles to the south of Ibrahim Zai in the Kohat district.

Mica.

Hazara district.

The Geological Survey of India were recently informed that an application had been made for a lease to mine mica and beryl from a small area near Giddarpur (34° 28′ : 73° 8′) in the Hazara district. Details of the occurrence are not known, but it is possible that the area will be visited by the Geological Survey of India in the 1939-40 field season. There is no reason why workable deposits of mica should not be found in the pegmatites accompanying Hazara granite, though such have so far not been met with.

Mineral Waters.

There are innumerable springs throughout the North-West Frontier Province; but I know of none which has special mineral contents. However, by bringing the matter to the attention of the district and State authorities concerned, and by analysis of samples of various waters, much useful information can be obtained. A survey of the mineral springs of India will commence in the 1939-40 field season, and in due course the springs of the Frontier Province will be examined and reported upon.

Nickel-ore.

North Waziristan.

In the course of a preliminary traverse through North Waziristan, I collected a specimen of serpentine from three-quarters of a mile E. S. E. of Pai Khel (32° 58′ : 69° 50′), near mile 54 on the Datta Khel road, with a "bloom" that was found to contain nickel. The specimen does not indicate the occurrence to have any economic value. It was also tested for cobalt and chromium with negative results, though a thin section of the serpentine showed possible chromite in minute flakes.

Ochres.

Chitral.

The decomposition of the pyrites in the Sankol shales has led to the formation of small deposits of red and yellow ochre. The latter occur close to and along small springs. These deposits are used locally as colouring material, but Tipper states that they are too small to have any other value.

Oil-shale.

Kohat district.

Oil-shale occurs in the Kohat district at Banda Daud Shah (33° 16′ : 71° 11′), Dharangi (33° 16′ : 71° 13′) and Kark (31° 7′ : 71° 5′). As a result of my examination of these, I concluded that if one seeks a source of fuel—carbonaceous or petroliferous—in the North-West Frontier Province, one must turn elsewhere than to the oil-shales of Kohat. I added that even if the oil-shales were of possible economic value in view of modern methods of low temparature carbonisation, the structural conditions under which they occur are such as to preclude any attempt to mine or quarry them on a commercial scale.

There are two bands of oil-shale cropping out along the right bank of the Tarkha Algad, north-east of Kark, interbedded with massive and thin-bedded gypseous shales; the upper band is some ten feet thick, and the lower band thicker, but only the upper four feet seems to be bituminous. This ? Laki oil-shale and gypseous series occurs just above the salt marl and it is very contorted. The same sequence can be traced westward to the salt mines north-west of Kark. A sample of the oil-shale sent by the Director of Agriculture, gave 38 gallons of crude oil per ton of shale and the tar of the crude oil gave a yield of 6·13 lbs. of ammonium sulphate per ton of

shale, the yield of tar and ammonium sulphate being low compared with specimens from Assam.

Two bands of oil-shale, associated with a gypseous series, and occurring just above the salt marl, were noted in the Dharangi stream after passing the Kirthar limestone, which is faulted against the ? Chinjis south of the hills. Here, also, the beds are very contorted, though, as at Kark, oil-shale can generally be seen along the stream course owing to undulations and puckering of the strata. A sample of the more carbonaceous shale gave 8 gallons of crude oil of specific gravity 0·88 per ton of shale, equal to 3·2 per cent. of crude oil by weight. A second sample from higher up the stream gave 0·9 gallons of crude oil per ton of shale. Further upstream still, I noted the oil seepage described by Pascoe; this is higher in the sequence than the oil-shales mentioned above, but the structure of the rocks is not such as to indicate any possibilities of finding oil here in commercial quantities.

Five furlongs E. N. E. of Banda Daud Shah, in the Laki series immediately underlying the Kirthar Nummulitic Limestone, I noted oil-shale associated with contorted, massive, thin-bedded, gypseous shales north of the E. W. fault which separates the Lower Eocene to the north from the ? Chinjis to the south. These are the same rocks as at Dharangi, the strata, however, being interrupted through faulting and other causes. A sample of the oil-shale gave 17·9 gallons of crude oil of specific gravity 0·90 per ton of shale, equal to 7·2 per cent. by weight of crude oil.

Petroleum.

Bannu and Dera Ismail Khan districts.

As far as is known at present, there is nothing to indicate that petroleum occurs in sufficient quantity in the North-West Frontier Province to be worked commercially. Three test wells have been drilled by the Indo-Burma Petroleum Co., Ltd., on the northern end of the Marwat range, eight miles west of the Kundal (32° 35′ : 71° 18′) seepage. The first well was abandoned and plugged at 3,662 feet and no oil or gas was encountered. The second well was abandoned 2,410 feet and no oil and gas was encountered. In the third well, again, no oil or gas was encountered and the well was abandoned at 2,614 feet.

In the continuation of the Trans-Indus range to the west of Pezu (32° 18′ : 72° 42′), a considerable gas seepage occurs at the faulted

crest of an anticline in Siwalik rocks. However, the usual source rocks of the oil are believed to be absent in this region, and the gas may be associated with lignitic deposits of Mesozoic age.

Samples of oil from Mughal Kot (31° 27′ : 70° 5′) in Shirani country were examined in Calcutta and pronounced of excellent quality. However, the prospects of obtaining oil in paying quantities are considered unfavourable.

Kohat district.

Test wells have been drilled unsuccessfully near Panoba (33° 37′ : 71° 54′) in the Kohat district.

General notes.

Every possible assistance should be given by the Local Government to companies of good standing which wish to prospect and prove the petroleum resources of the province. It is quite possible that geophysical means of prospecting may lead to the discovery of structures beneath the alluvium which are suitable for the retention of oil and gas. When these are discovered and it is desired to test them by drilling, every possible encouragement should be given for the successful prosecution of this work.

Platinum.

Kohat district.

A. B. Wynne states that platinum is reported to occur with stream gold washed in the Indus, ? in the Kohat district; but no details are available.

Precious Stones.

Chitral.

While in Chitral, Tipper discovered that a large area in the western part of the State, forming the high ground between Afghanistan (Kafirstan and Wakhan) and Chitral, is composed of garnetiferous and chiastolite-bearing schists with large masses of granite intrusions. These intrusions are variable in size and mode of occurrence, and are generally fine-grained. The intrusions sometimes occur parallel to the planes of schistosity, but at other times cut through the schists at all angles converting the mass into a breccia on a large scale. In one of the coarser intrusions at Sirwigh-o-gaz (12,000 feet), a summer grazing ground on the road from the Lutkuh to the Arkari, beryls occur. A few beryls of poor quality, white and badly flawed were seen

in situ. In the sandy debris below the rock, good hexagonal crystals can be found in considerable quantities. These are of very pleasing colour, the majority being rather badly cracked and containing lines of inclusions parallel to the basal cleavage. Some of the specimens are, however, almost of gem quality and the locality is worth further prospecting.

In Chitral Tipper also found that garnets are widely developed and occur in the banded gneisses, in garnetiferous schists and in the granitic rocks cutting the latter. Many of the garnets are of pleasing colour, but are usually too flawed to be of value as gem-stones.

Hazara district.

Application was recently made for a mining lease for the extraction of beryl, as well as mica, from a small area near Giddarpur (34° 28′ : 73° 8′) in the Hazara district. Though no further details are at present available, it is hoped that this locality will be visited by the Geological Survey of India in the 1939-40 field season.

Salt.

Kohat district.

The salt of the Kohat district is being developed by the Northern India Salt Department; and presumably the amount produced is regulated by the requirements of that Department and are controlled by various factors entailing a consideration of output on an all-India basis.

According to La Touche, allusion to the existence of extensive beds of rock-salt in the district was made in 1843 by Agha Abbas and later by Verchère and Oldham; but it was not until the year 1874 that an adequate description was published. In that year, a report by Wynne and Warth was drawn up, giving a complete account of the geology of the region and of the economic development of the salt.

The rock-salt occurs in beds of great thickness, measuring in one instance at least a thousand feet, at a single distinct horizon overlain by nummulitic limestone. The beds of rock-salt are exposed in the axis of a series of narrow, elliptical, anticlinal folds, so that the outcrop is never continuous for any great distance. The salt is of great purity and differs from that of the Salt Range in being greyish in colour and not possessing a reddish tint.

The salt occurs at Jatta (33° 19′ : 71° 17′), Bahadur Khel (33° 11′ : 70° 57′) and Kark Kharak (31° 7′ : 71° 5′) on a scale sufficient to supply the local demand, including export in the Trans-Frontier tract and Afghanistan. According to Gee, the annual output from these three places is about 21,000 tons. Figures for the production in the Kohat district are given in Tables 1 and 2 on page 11.

At all three localities, the salt is worked in a number of small quarries and is extracted by hand. Bands of clay and sand are intercalated with the salt. The deposits near the surface are so extensive that working to any appreciable depth is unnecessary. Formerly salt was also quarried at Malgin (33° 18′ : 71° 30′), 13 miles east of Jatta. Gee states that there is no doubt that there is sufficient outcrop salt at the above-mentioned places and at other fairly accessible localities to meet the demand by quarrying only for many decades.

North Waziristan.

A report having been received to the effect that salt was being manufactured in Waziristan, an officer of the Northern India Salt Revenue Department visited the locality. He reported that the salt site is situated at Arap Kot (32° 44′ : 70° 15′), which is on a bend of the Shaktu river just within North Waziristan and is some 20 miles north-east of Sararogha Fort (South Waziristan). It consists of a small spring of brine emanating from a conglomeration of stones and clay at an old subsidence above the bed of the Shaktu. No sign of salt marl or exposure of rock-salt was observed.

Steatite.

Peshawar district.

An exposure of soapstone, or steatite, occurs less than a quarter of a mile north-west of Kund (33° 56′ : 72° 14′) in the Nowshera tahsil of the Peshawar district. There seems to have been alteration by magnesium and siliceous solutions of the Attock slates, which have approximately an E.-W. strike. When I visited the occurrence, I noted that the zone of alteration follows the foliation direction of the shales or slates towards the Katti Miana occurrences. White reef-quartz occurs in the zone of alteration. The soapstone has been quarried and mined for some considerable time; but the pits have now mostly been filled and it was impossible for me to ascertain the extent of the ancient working. The material has been used

locally for soap-making and for white-washing after being powdered. It is much purer than the Katti Miana occurrence.

Half a mile north-west of Katti Miana (33° 56′ : 72° 12′) along the continuation of the strike of the Kund deposit described above, there are some pits in the precipitous sides of a hill on the right bank of the Katti Miana stream flowing north-east to join the Kabul river by Nihalpur. The Attock slates are badly crushed here. The local inhabitants used to quarry impure soapstone mixed with shale shingle. This was powdered and mixed with water, so that the material remained in suspension and the shingle fell to the bottom. Then the suspensoid was made into cakes, which were sold at an anna a seer and used for white-washing houses, etc. Although greenish when quarried, the material became white when powdered and dried.

I concluded that there would be little purpose in spending money to develop and prove the Kund deposit, unless it be to supply a purely local market, as the quality and quantity could not hope to compete with the better deposits at present being worked in India elsewhere.

Sulphur.

Chitral.

On the left bank of the Arkari, opposite the village of Mujhigram, a small deposit of sulphur, contaminated by earthy matter, was observed by Tipper. Sulphuretted hot springs are of common occurrence in the neighbourhood of the granite intrusions in Chitral, and Tipper was of the opinion that the sulphur has been deposited from one of these springs. The deposit, though interesting, has no appreciable economic value. The sulphur has been used locally for the manufacture of gunpowder.

A sample of crude sulphur was received recently by the Imperial Chemical Industries (India), Ltd., which was believed to have come from Chitral. It consisted of a portion of a block cast in a mould, and apart from the lower layer, which contained a large proportion of impurities, the balance appeared to be of good quality. The following two analyses of the sulphur extracted and moulded were made by the firm in question and are reproduced here with its permission. It should be noted that there is a considerable amount of impurity in this prepared sulphur which has settled to the bottom of the prepared block. It has also been stated

that the arsenic content given must be regarded as an indication only, and not an accurate analytical figure :—

	LOWER LAYER.	UPPER LAYER.
	Approximately 20 per cent of total thickness.	Approximately 80 per cent of total thickness.
	Per cent.	Per cent.
Loss at 100°C. for one hour (moisture)	0·90	0·08
Non-volatile matter (ash) . . .	15·08	0·46
Sulphur	84·0	99·4
Chlorides as Na Cl	0·05	0·03
Acidity as H_2 SO_4	0·04	0·02
Arsenic	Less than 0·04	0·04
Organic matter (approximately) .	0·67	0·1
TOTAL .	100·78	100·13
Appearance (colour) . . .	Greenish	Yellowish

It is possible that this sample was obtained from the Mujhigram area, but confirmation is lacking.

Tipper also found that a large area in Chitral on the borders of Afghanistan and between the Lutkuh and Arkari valleys is occupied by garnetiferous and other schists, cut through by granitic intrusions. At many places these schists contain patches of sulphides, chiefly pyrites and pyrrhotite, accompanied by what appeared to be löllingite, the arsenide of iron. The minerals weather out in nodules covered with a thick skin of iron oxides. The minerals were tested for nickel with negative results. It would seem, therefore, that these mineral patches, generally small in extent, are of very little value. Tipper also noted a vein of pyrites, a quarter of an inch wide, in granite in the Barzin valley.

Dera Ismail Khan district.

Traces of sulphur were observed by La Touche in Upper Nummulitic beds near Domunda (31° 36′ : 70° 14′) in the Shirani country, apparently formed by the decomposition of iron pyrites.

Kohat district.

Sulphur pits were formerly worked in a band of pyritous (alum) shales lying below a limestone scarp on the western bank of the Indus river near Khushalgarh. The mode of occurrence of the mineral at Luni-ki-kassi (33° 36′ : 72° 1′) and at Panoba (33° 37′ : 71° 54′) was described by Lyman in a supplement to his report on the Punjab oil lands; and at Gunjalli (33° 25′ : 71° 50′) by Wynne. The sulphur is produced

by the decomposition of the pyrites in the shales, which appear to be very carbonaceous, and collects in its native form on the sides of small crevices in the rock. It was extracted by a simple process of sublimation in earthen vessels, one being placed on the fire and another inverted over it mouth to mouth, so as to catch the fumes.

Wynne mentions the appearance of once extensive sulphur or alum works on the right bank of the Indus near Dandi hill station. These are situated on the road from Chorlakki to Dandi (33° 36′ : 71° 59′), about two miles from the latter.

Pascoe mentions that sulphur pits about 1,000 yards east of Panoba village used to be worked before the British Rule.

Mardan district.

I have been informed that pyrites occurs as a vein in a well sunk at Gandal (34° 7′ : 70° 41′) in Gadun tribal territory, and was shown a specimen said to have been collected from the dump of the well. It was added that the thickness of the vein was nine feet, an obvious exaggeration, and that samples, presumably from the dump and not from the actual vein, have been taken to Peshawar for trial. It was not possible for me to visit the area, but an examination may be made during the 1939-40 field season. The economic importance of a large vein of pure pyrites would be great.

South Waziristan, etc.

Pyrites occurs as small crystals and concretions in certain of the shales, limestones and schists in South Waziristan, Peshawar district, Mardan district, Kohat district, etc., but these occurrences have no economic value.

Water-supply.

Bannu district, etc.

The Bannu, Dera Ismail Khan and Kohat districts are greatly in need of schemes that will develop their scanty resources of surface and underground water-supply. Each area has to be considered in the light of its own peculiar geographical and geological conditions.

Hazara district.

As I consider one may discount the economic possibilities of the Dore river coal, I invite attention to the hydro-electric possibilities of the perennial streams in the Hazara district; a glance at the degree sheet 43 F will show how well the district is provided with these. The Dore river would be rather difficult to dam at some such place as just below the

junction with the Harnow *nala*. Though the Nummulitic limestone on the right bank would offer a good foundation, a fold-fault runs along the course of the stream. Damming would flood the lower part of the Harnow and would cause such expense in the provision of bridges, etc., for the Abbottabad-Nathiagali road. Also the stream is very subject to spates and enormous amounts of detritus are carried down by it.

The Harnow *nala*, apparently, has a perennial flow. It has a very steep gorge which should be easy to dam below Jhafar without inundating any land of value. Whether the capacity of such a dam (provided the extent of the flow of the Harnow would be sufficient to replenish the supply) would suffice to provide power for the Hazara district is a matter for the engineers concerned.

In my opinion, however, recourse could very easily be made to the more suitable stream, the Kunhar, along the course of which, no doubt, suitable alternative sites could be found for dams which would easily supply the whole of the Hazara district with power.

Peshawar and Mardan districts.

The surface water-supply is developed in the Peshawar and Mardan districts by the Upper and Lower Swat Canals. However, much of the water in these canals and the distributaries is wasted by the local inhabitants and the problem of preventing this waste has occupied the attention of local authorities for some considerable time. One of the suggestions that seems to have much in its favour is the proposal to lower the levels of these canals and their distributaries, so that it would not be possible for water to flow on to the land of the local cultivators. In other words, all water would have to be pumped to the land and a charge made for the amount of water consumed. Besides preventing waste and waterlogging of arable land, this method has the advantage of providing a good load for the power of the Malakand hydro-electric scheme.

There seems a little doubt, also, that the scanty local surface water resources of the Peshawar and Mardan districts could be conserved by dams constructed so as to impound flood water to the north of the Upper Swat Canal. The utilisation of the water so impounded would mean that more water would be available than at present during the period of greatest demand on the canals, *i.e.*, during September and October. One possible site for such a dam would be across the Badi Khwar where it meets the Machai branch of the Upper Swat Canal.

In a recent paper, I have discussed the underground water-supply of the Peshawar and Mardan districts and added an appendix on the Kohat valley. Amongst the points discussed therein are the question of a piped water-supply for the town of Hoti-Mardan, which is very urgently needed, and the further development of water resources of the areas north of Machai branch of the Upper Swat Canal. Amongst areas singled out for particular attention may be mentioned the Kharkai, Khui Barmol, Upper Katlang, and Upper Rustam valleys.

POSSIBILITIES OF MANUFACTURE OF CEMENT.

I have outlined the possibilities of the manufacture of cement in the North-West Frontier Province in a letter sent to the Hon'ble the Chief Minister in November, 1938.

Portland cement is so greatly more important than any other cement of its class that I shall confine most of my remarks to it. It consists of a mixture of compounds of lime and silica and of lime and alumina. These are the essential consituents, but it commonly contains in addition loose compounds of lime with ferric oxide, magnesia and small quantities of inert insoluble silica or silicates, alkalis and sulphates. Except when perfectly calcined and absolutely fresh, it also contains a little water and carbonic anhydride absorbed from the air. The ultimate composition of Portland cement varies with the nature of the raw materials from which it has been made. The limits laid down by the British Standard specification are as follows: --the proportion of lime to silica and alumina shall not be greater than the maximum nor less than the minimum ratio (calculated in chemical equivalents) represented by $\frac{Ca\,O}{Si\,O_2 + Al_2\,O_3} = 2{\cdot}85$ or $2{\cdot}0$ respectively; the percentage of insoluble residue shall not exceed 1·5 per cent.; and the total sulphur content calculated as sulphuric anhydride (SO_3) shall not exceed 2·75 per cent. The total loss on ignition shall not exceed 3 per cent.

As would be expected, the raw materials from which Portland cement can be prepared are of the most varied description. Chalk, limestone, or any other approximately pure form of calcium carbonate on the one side, and clay, shale or any typical argillaceous material on the other, are burnt together to produce Portland cement, provided that the product has a composition within the limits already laid down. It follows, naturally, that substances which

contain both calcium carbonate and clayey matter, such as calcareous shales and argillaceous limestones, can be similarly used. On this account, and because of the low price of the manufactured article, and the consequent high proportion which freight bears to the total cost at the point of consumption, the manufacture of Portland cement is not confined to any particular spot, but is successfully undertaken wherever deposits of suitable raw materials occur, *provided the cost of fuel* is not extravagantly high. The quality of Portland cement and its suitability for building purposes is ascertained by various mechanical tests and by its chemical analysis. The analysis shows whether the constituents fall within the recognized limits stated above, and detects the presence of adulterants such as blast furnace slag, etc. But as it is impracticable to make a *proximate* analysis of Portland cement, the ordinary analytical figures will not indicate whether the raw materials have been sufficiently intimately mixed and sufficiently thoroughly burnt to form those cementatious substances constituting sound and serviceable Portland cement. This question, however, can be staisfactorily settled by physical and mechanical tests, which are laid down under British Standard specifications.

The original object of manufacturing Portland cement and similar substances was to obtain a material which would both set and would resist the action of water. But it was soon found that the great mechanical strength of Portland cement made its use advantageous even when it had not to be exposed to water, and at the present day it is the structural cement most commonly used; and on account of the great decrease in cost of modern manufacture, it tends to displace all other building cements, including common lime.

With these preliminary remarks, we may now consider local conditions. Portland cement is being manufactured at the eastern termination of the Hasan Abdul hill, in the village area of Wah by the Punjab Portland Cement Co., Ltd. The raw materials used are Laki limestone from the Hasan Abdul hill, showing on analysis up to 98 per cent. of calcium carbonate, alluvial clay, which is dug up close to the works, and gypsum, which comes from Khewra in the Salt Range. The limestone and clay are mixed in the proportion of 3 : 1. The raw materials are crushed and ground with water to produce a very fine slurry, which is burnt in three rotary kilns at about 2,800°F. The burning is carried out by firing the rotary kilns with pulverised coal and the resultant clinker produced is

then ground in compound mills to form cement. During the grinding operation, gypsum is added to the clinker in a very small amount in order to control the setting time. The fuel utilised is the friable coal from the Simpson group of mines of the Makerwal Coal Co., Ltd., at Trag in the Mianwali district of the Punjab. On account of high freights, the poorer, but nearer, Trans-Indus Salt Range coal from Trag is able to compete successfully with the better, but more distant, coal from Bengal and Bihar. However, the manufacturers have found also that the softer coal from Trag has, in fact, certain advantages and they have modified their manufacturing process accordingly.

I have noted above the desirability that the cost of fuel should not be extravagantly high. When the question of the establishment of a cement works in the Frontier Province is being considered, the point that immediately arises is the source of supply of fuel. In my several reports to the Government of the North-West Frontier Province, I have pointed out the absence of any assured supply of coal of good quality. I have visited the Hazara occurrences and concluded that even with modern methods of low temperature carbonisation, and of washing the possibilities of the Dore river coal being worked on any commercial scale may be discounted. I concluded that as a potential source of fuel for the North-West Frontier Province, the Dore river coal may be ruled out. In any case, the freight of the Dore river coal, were it ever worked, would be at least equivalent to that to the Trag coal of the Punjab.

I have recommended that efforts should be directed towards proving the coal to the north of the Baroch gorge in the Kohat district, but that coal would, if proved, have to be worked from the Punjab (Mianwali) side. As I have stated elsewhere in this paper, I understand that the Makerwal Coal Co. have a lease of this area and have been prospecting it, together with other areas in the adjoining part of the Mianwali district of the Punjab to the north of thier present mines at Trag.

If a cement works were established in the Frontier Province, then as I do not consider the Kohat oil-shale need be considered in this connection, the fuel for the manufacture of the cement would either have to be brought by rail from Bihar or Bengal or from the Mianwali district of the Punjab. The freight from the latter area would be less, but the pit-head price of the coal would be higher than that of Bihar or Bengal coal on account of the methods of

extraction used. Also there is the question as to whether the Makerwal Coal Company could guarantee to maintain a sufficient supply of coal to satisfy the Punjab Portland Cement Works at Wah, the new proposed cement works in the Frontier Province, and also the Coal Company's present customers in other parts of the Punjab to whom they supply coal for brick manufacture, etc. The proposed works in the Frontier Province would be entirely dependent upon supplies of coal from here as, presumably, it would be uneconomic to import coal from Bengal and Bihar. In any case, the cost of Trag coal delivered to any part of the Frontier Province will be greater than what that same coal costs the Punjab Portland Cement Co., Ltd., at Wah. However, the increased cost of fuel can be offset against the lesser freight that the Frontier Province proposed works would have to pay to deliver its finished product to the consumer, if he be in that part of the Frontier Province west of the Indus.

Turning to the question of raw materials, there is abundant limestone in the Frontier Province, in close proximity to which I have little doubt suitable clay or shale will be found. One calls to mind the large limestone ridge on which the hill-station of Cherat is built, the limestone and marble ridge forming Ghundai Tarako on the border of Swat and the Mardan district, the marble and limestones near Swabi, other possible supplies between Swabi and Jahangira, the very large supplies of the Mullagori area and other parts of the Khyber Agency, and the numerous limestone hills of the Kohat district. With the exception of the Khyber supplies, which may be debarred on strategic grounds, none of these supplies are very close to the main railway line to Peshawar. Supplies of gypsum which is used, amongst other uses, for the manufacture of various kinds of wall-plasters and cements, could undoubtedly be obtained from some of the Tertiary beds in the Kohat district; even if supplies are not readily available from here, they could be imported from Khewra.

However, it will be gathered that I am not at all optimistic that a cement works in the North-West Frontier Province would be able to compete successfully with the Punjab Portland Cement Co. at Wah in the Attock district of the Punjab.

SUMMARY.

It must be admitted that the North-West Frontier Province has been unfavourably blessed by Nature with supplies of minerals of

economic importance, excepting as regards building stones, which are composed chiefly of limestone and marble. Its list of mineral resources does not make hopeful reading and it is, indeed, hard to suggest minerals, to the development of which activities could with advantage be directed. It has abundant power available from the Malakand hydro-electric scheme, which has been functioning now for a few years, and every encouragement should be given to industrial enterprises which wish to take advantage of this power.

The development and proving of the coal of the Surghar range on the border of the Kohat district with the Mianwali district of the Punjab, should be undertaken or encouraged as soon as the results of the present survey by the Geological Survey in the latter district are known. The limestones of the Province occur in almost inexhaustible amount and it is well blessed by deposits of good quality white statuary marble. The latter should be carefully conserved and the handsome banded marbles, which occur in great abundance, should preferably be used for ordinary building purposes. The gypsum of the Kohat district could possibly be developed by the establishment of a local industry. And, finally, considerable attention could and should be given to the development of the surface and underground water-supplies of the districts of Peshawar, Mardan, Kohat, Bannu and Dera Ismail Khan. The establishment of a cement works is not advocated.

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INTRODUCTION.

In view of its importance, the problem of the most efficient technical methods of utilising coal has become of fundamental interest in many countries in Europe and has been engaging the attention of the Government of India and others in this country. The dominant feature of the coal industry in general should be in the availability of reliable experimental data and their utilisation for industrial purposes such as iron smelting, etc. The outstanding problem that faces the iron and steel industry as a whole depends upon the most economic utilisation of fuel, especially of coking

coals which are essential for the production of good metallurgical coke for smelting iron ores. This problem has been a topic of repeated discussions and experiments.

Regarding the origin, occurrences, quality and the constitutions of Indian coals four important Memoirs have been published by the Geological Survey of India :—

(1) C. S. Fox—'The Natural History of Indian Coal', *Mem. Geol. Surv. Ind.*, LVII, 1931.

(2) C. S. Fox—'The Jharia Coalfield', *Mem. Geol. Surv. Ind.*, LVI, 1930.

(3) E. R. Gee—'The Geology and Coal Resources of Raniganj Coalfield', *Mem. Geol. Surv. Ind.*, LXI, 1932.

(4) C. S. Fox—'The Lower Gondwana Coalfields of India', *Mem. Geol. Surv. Ind.*, LIX, 1934.

The Lower Gondwana fields are responsible for 98 per cent. of the total annual production of Indian coals and the rest (2 per cent.) comes from the Tertiary Coal Mines.

Based upon the above Memoirs, attempts have recently been made for the estimation of the amount of superior quality of coal in India. In 1935 Sir L. L. Fermor (Fermor, 1935, pp. 1-14), the then Director of the Geological Survey of India, dealt with this problem thoroughly in his paper 'India's Coal Resources'. According to Dr. Fox the reserves of coking coal of metallurgical quality are as follows :—(*op. cit.*, p. 5)

	Million Tons.
(1) Giridih	30
(2) Raniganj	250
(3) Jharia	900
(4) Bokaro	320
(5) Karanpara	not estimated.
	1,500

But when the vast quantity of the best quality of iron-ore deposits of India is taken into consideration, it is found that iron-ore deposits of Bihar and Orissa alone contain 3,000 million tons (*op. cit.*, p. 5). To obtain pig-iron from this ore by methods at present in vogue, good metallurgical coke is necessary and for this purpose, about 3,000 million tons of coking coals are indispensable if our iron and steel industry is to thrive. In other words, our iron-ore deposits of Bihar and Orissa require more than the total amount of all good quality

coals—coking and non-coking combined together. Considering the present method of extraction of coals from the mines and the annual production of coal, the conclusion arrived at is very alarming, for the good coking coals will be available only for a limited period for smelting the iron-ores (*op. cit.* pp. 8-9). This disappointing fact which is so detrimental to the growth of the iron and steel industry, drew the serious attention of the Government of India and a Coal Mining Committee was appointed in 1936 to devise measures for conserving the coal assets of this country by improving the methods of extraction and preventing avoidable waste. The recommendations of the Committee regarding the safety and conservation have been published in 1937.

The aim of this investigation on coking coals is to study the physical and chemical characteristics which are of extreme importance for the manufacture of metallurgical coke.

It will be of considerable interest to note how the production of pig-iron and steel has been increasing year by year and naturally the consumption of good coking coal has also been increasing. This will be evident from the following tables:—

TABLE 1.—*Production of Pig Iron, Steel, Ferromanganese (in tons) in India.*

(Committee, Coal Mining, 1937, p. 239.)

Year.	PIG.					TATA'S.	
	Tata.	Bengal Iron.	Indian Iron and Steel Co.	Mysore Iron Works.	Total.	Steel.	Ferro-manganese.
1931 . .	779,545	..	243,214	15,577	1,058,336	489,134	14,336
1932 . .	689,931	..	198,700	14,683	913,314	480,338	336
1933 . .	793,953	..	249,079	14,805	1,057,837	505,429	7,725
1934 . .	882,054	..	420,271	17,885	1,320,210	596,981	5,536
1935 . .	897,976	125,850	480,884	19,152	1,451,862	627,867	14,182
1936 . .	858,272	..	659,543	22,241	1,540,056	660,291	3,263
1937 . .	885,398	..	713,030	22,837	1,621,260	665,309	8,041

TABLE 2.—*Quantity of hard coke manufactured in India (in tons).* (Committee, Coal Mining, 1937, p. 237.)

Year.	Total Hard Coke.	Jharia Coal.	Giridih Coal.	Raniganj Coal.	Other Coals.	Total Coal used up.
1931 . .	1,309,093	1,687,681	33,209	12,456	24,558	1,757,904
1932 . .	1,214,772	1,585,733	32,724	12,878	7,330	1,638,665
1933 . .	1,227,746	1,517,483	27,245	10,469	2,898	1,658,095
1934 . .	1,517,187	1,934,048	26,207	80,924	2,698	2,043,967
1935 . .	1,766,821	2,232,807	26,740	91,085	2,859	2,353,441
1936 . .	1,811,291	2,233,886	37,570	92,302	2,970	2,366,728
1937 . .	1,886,853	2,472,182	72,240	83,925	9,305	2,637,652

From the above, it is clear that nearly all the metallurgical coke is produced from the Jharia coals except a very small fraction which is obtained from the coals of Giridih and Raniganj and other coal fields. Owing to this peculiar significance of the Jharia fields, the majority of the samples for investigation has been selected from the Jharia field. On the physical and chemical behaviour of Indian coals, there has been but a very limited number of investigations.

Earlier Work.

Rassow and Bhattacharjee (1926, pp. 250-264) studied the low temperature distillation and Fermor (1930, pp. 189-288) investigated the relation between the ash content and the specific gravity of Indian Vitrains. Dutta Roy (1934, pp. 21-42) investigated the action of solvents on Indian coals. By pressure extraction some important clues were obtained regarding the constitution and structure of Indian coals. Later on, Dutta Roy and Bhattacharjee (1934, p. 67) made a comparative study of the high temperature and low temperature distillation of Indian coals and Hoffman and Dutta Roy (1934, p. 428) made a thorough study on the chemical and physical properties. Recently Bunte Bruckner and Sanjana (1935, p. 350) made studies on coking properties and C. Forrester (1936, pp. 173-224) studied the chemical and physical characteristics of the Barakar Coals.

Object and Method of Investigation.

To obtain comprehensive data regarding the manufacture of good coke for metallurgical purposes it is deemed necessary to study the following characteristics which are of fundamental importance :—

(I) Caking Index.

(II) Swelling properties.
(III) Decomposition and softening points.
(IV) Blending.

The samples. used for the present investigations, are true representative samples of different collieries as despatched to Messrs. Tata Iron & Steel Co. Ltd., and I take this opportunity of thanking them for so kindly placing the samples at my disposal.

1. CAKING INDEX.

Various investigations on coking coals for their utility for the blast furnace have been made and attempts have also been made to correlate analytical data with the caking properties. When producing metallurgical cokes, it is of utmost importance to use coking coals. But coking coals are coals which under modern coke-oven practice yield metallurgical cokes of good quality and reactivity.

For selecting coals for coke-oven the caking index affords good clues and these clues may be correlated with the production of coke as well as by-products.

The caking-index is the estimation of coking properties of coal based on the mechanical strength of the coke-button obtained by heating a mixture of the coal and some inert material.

There are various methods in use for the estimation of caking-index. Since the invention of a simple method by Richters (1870, p. 71) which consists in mixing coal with some material which is inert and observing the capacity of producing coke-buttons which are then subjected to some mechanical tests regarding strength, various modifications by different authors have been made and special mention may be made of the work of Campredon (1895, p. 820), Audibert (1926, pp. 115-136), Gray (1923, p. 42), Damm (1928, p. 1073), Marshall and Bird (Tech. Pub. 216, p. 46) and Kattwinkel (1932, p. 103).

The method of Campredon was followed and it consists in mixing finely powered coal and sand (76 mesh) in various proportions to make a total weight of 5 gm. On carbonising the different mixtures in standard platinum crucibles for 6 minutes, the respective mixtures are seen to yield a coherent button and a powdery residue. The individual buttons are then subjected to a load of 500 gm. and the button which can just stand this weight is noted. The proportional weight of the inert matter (sand) used in the original mixture

from which this button resulted, represents the caking-index of the coal. Supposing a button, produced by a mixture of coal and sand in the ratio of 1 : 14, can just stand the weight of 500 gram, then 14 will represent the caking-index. As the caking-index depends upon the specific properties of Coal, the studies of the following relations have been made :—

(1) Relation between caking-index and proximate analysis.

(2) Relation between caking-index and ultimate analysis.

(3) Relation between caking-index and the high temperature distillation.

The proximate and ultimate analyses were performed according to the standard methods in vogue. In case of the volatile matter, the temperature at which the determination was made, was recorded as 950°C. The percentages of carbon and hydrogen were found out by the usual combustion methods and the percentages of nitrogen and sulphur were estimated by the well-known Kjeldall and Eschka methods respectively. As there is no satisfactory method for the estimation of Oxygen, the percentage of oxygen is generally expressed by the difference of the sum of the percentages of all other constituents from hundred. This value of oxygen cannot be strictly correct as this is likely to be contaminated with experimental errors in other determinations. So it is evident that the value of oxygen should be expressed as 'oxygen+error'.

The high temperature distillation was carried out in a silica tube in an electric furnace at 950°C. As the object of this was to find out the coke yield and by-products, it was thought necessary to carry out the distillation under conditions prevailing those in coke-ovens. For this purpose about 10 grams of crushed silica brick was placed just at the mouth of the silica tube and the gases were allowed to pass through these pieces of bricks. 20 grams of coal was put in the silica tube and the distillation was carried out as usual—coke remained in the tube and the Tar and NH_3 were absorbed in a recovery train and the gas was collected with help of the aspirating bottles which were saturated with NaCl and by-product gas.

From the tables 3 and 4 it is evident that the coals of Barakar series belonging to the Jharia field have higher caking-indices than those belonging to the Raniganj series of the Raniganj field. The moisture-content of the former hardly exceeds 2 per cent. while that of the latter ranges from 3 to 10 per cent. Thus caking-index

bears an intimate relationship to the moisture-content of the coal. This fact also confirms the previous observations of author (Dutta Roy, 1934, pp. 11-12). The determination of the hygroscopicity of coals of Jharia field and of the Raniganj field was carried out and it was found that the Raniganj coals had more moisture-absorbing power than those of the Jharia field.

The ash-content of the coal, however, does not bear any direct relationship to the caking-index. With regard to the caking-index and the fuel-ratio, it appears from the table that the caking-index varies directly as the fuel-ratio. Moreover it is noteworthy that the fuel-ratio in the case of the Barakar series ranges from 2 to 2·8 while in case of Raniganj series it never exceeds 1·5.

Again the ultimate analysis reveals the fact that there exists a definite relation between the caking-index and the carbon and oxygen contents of coal. The caking-index increases with the increase in the carbon-content while it decreases with the increase in the oxygen-content.

Further, the relation between the caking-index and the high temperature distillation products is of great importance. It is evident from the table that coals having higher caking-indices produce a higher amount of good metallurgical coke whereas coals of lower caking-indices yield a poor coke but a higher amount of by-products (tar, gas, etc.) of superior qualities.

Considering the practical utilisation of cokes for smelting the iron-ores, it is found that medium caking coals (caking-index varying from 13 to 15) serve best the coke-oven practice, in order to obtain good metallurgical cokes as well as by-products.

Although, caking-index affords valuable clues for selecting coking coals for use in coke-ovens, it serves only as a relative criterion, for it has been found by experience that even when using coking coals with requisite caking-indices, we cannot always predict the nature of the coke produced. The cause of this anomaly must be ascribed to the properties of the constituent parts of coal. Wheeler and his co-workers (1913, p. 1704, 1916, p. 707, 1927 p. 700) studied the action of pyridine on coal to find out its constituent parts and they separated the coal into three parts, namely—α, β and γ compounds. They found that the γ-compound was responsible for coking properties. But the classical researches of Fischer and his co-workers (1925, p. 33) threw much light on this obscure subject and they extracted the coal with benzene under pressure and the extract thus obtained

TABLE 3.—*Results showing the relation between caking-index, proximate analysis and ultimate analysis.*

Colliery	Seam.	Series.	Proximate Analysis.					Ultimate Analysis.					Ultimate Analysis calculated on moisture-free & ash-free basis.					
			Mois-	Ash.	V. M.	F. C.	C./V.	C.	H.	N.	S.	O.	C.I.	C.	H.	N.	S.	O.
			Per cent.	Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
JHARIA FIELD.																		
Jamadoba . .	18	Barakar	1·76	14·30	28·56	55·38	1·94	71·80	5·04	1·70	0·47	4·93	14	85·51	6·00	2·02	0·56	5·91
Do. . .	17	Do.	1·45	10·10	28·30	60·15	2·13	75·52	5·72	1·88	0·44	4·91	16	85·41	6·47	2·13	0·50	5·49
Sijua . . .	16	Do. .	0·80	18·10	24·76	56·34	2·28	69·78	4·72	1·55	0·54	4·51	18	86·04	5·82	1·91	0·67	5·56
Malkera . .	15	Do. .	0·90	13·80	23·60	61·70	2·61	74·12	4·50	1·66	0·57	4·45	16	86·91	5·27	1·95	0·67	5·20
Loyabad . .	15	Do. .	0·60	15·00	23·98	60·42	2·52	73·40	4·20	1·52	0·67	4·61	14	86·98	4·98	1·80	0·79	5·45
Gopalichak . .	14	Do. .	0·60	13·70	24·32	61·38	2·52	74·48	4·30	1·58	0·54	4·80	14	86·92	5·02	1·84	0·63	5·59
Bhulanbarari .	14 sec. A 27′ 6″.	Do. .	1·30	12·84	25·80	60·06	2·33	72·58	4·98	1·48	0·55	6·27	16	84·56	5·80	1·72	0·64	7·28
East-Balgora .	14 Sec. A 12′ 7″.	Do. .	0·90	16·78	24·32	58·00	2·38	71·08	4·96	1·47	0·57	4·24	18	86·36	6·03	1·79	0·69	5·13
Bhagatdih . .	13	Do. .	0·60	13·40	24·68	61·32	2·48	73·58	4·60	1·78	0·64	5·40	15	85·57	5·35	2·07	0·74	6·27
Kustore . .	13	Do. .	0·80	14·00	24·12	61·08	2·53	71·72	5·30	1·88	0·60	5·70	17	84·20	6·22	2·21	0·70	6·67
Kirkend . .	13 Sec. A 19′ 11″.	Do. .	0·80	13·42	25·20	60·58	2·40	73·07	5·03	1·72	0·56	5·46	18	85·13	5·86	2·01	0·65	6·35
Busserya . .	12 Sec. A.	Do. .	1·20	14·26	24·00	60·54	2·52	73·08	5·12	1·50	0·68	4·16	17	86·45	6·06	1·77	0·80	4·92
Sendra-Bansjora .	12 Sec. A 14′ 0″.	Do. .	0·82	16·40	22·56	60·22	2·67	70·80	5·00	1·49	0·64	4·85	15	85·53	6·04	1·80	0·77	5·86
Chetudih . .	12	Do. .	0·82	16·48	24·20	58·50	2·42	71·30	4·90	1·38	0·56	4·56	15	86·37	5·93	1·67	0·68	5·85
Kirkend . .	12	Do. .	0·68	13·67	24·32	61·33	2·52	72·90	4·30	1·68	0·35	5·92	16	85·15	5·61	1·86	0·41	6·97

Bhagatdih . .	12	Do. .	0·70	14·80	23·02	60·58	2·53	72·50	4·30	1·68	0·72	5·30	13	85·77	5·09	1·99	0·85	6·30
Ekrakhas . .	11,bottom 10′ 8″.	Do. .	0·78	16·20	23·00	60·02	2·61	71·50	4·60	1·70	0·40	4·82	15	86·16	5·54	2·05	0·48	5·77
Katras . .	11	Do. .	0·85	14·78	24·00	60·37	2·52	72·80	3·98	1·52	0·64	5·43	16	86·23	4·72	1·80	0·76	6·49
Ena . . .	11, bottom 9′ Sec.	Do. .	1·30	14·42	24·62	59·66	2·42	72·80	4·55	1·72	0·43	4·78	17	86·49	5·31	2·04	0·51	5·65
Bhagatdih . .	11, Sec. B.	Do. .	0·80	15·08	24·42	59·70	2·85	72·78	4·52	1·72	0·56	4·54	18	86·54	5·37	2·05	0·67	5·87
Kustore . .	11	Do. .	1·09	17·75	22·22	58·94	2·65	68·69	4·61	1·33	0·67	5·86	16	84·63	5·68	1·64	0·83	7·22
Do. . .	10	Do. .	0·55	18·44	22·64	58·37	2·58	70·20	4·62	1·50	0·66	4·03	13	86·67	5·70	1·85	0·81	4·97
RANIGANJ FIELD.																		
Seetalpur . .	Dishergarh	Raniganj	2·00	13·27	35·40	49·33	1·39	70·00	5·00	1·50	0·23	8·00	12	82·60	5·90	1·77	0·27	9·46
Dishergarh .	Do. .	Do. .	2·60	11·15	36·50	49·75	1·39	69·12	4·83	1·50	0·24	10·66	13	80·11	5·60	1·74	0·28	12·27
Aldihi . . .	Do. .	Do.	2·00	11·82	38·20	47·98	1·26	69·80	4·85	1·60	0·28	9·63	11	80·97	5·63	1·86	0·32	12·22
Parbelia . .	Do. .	Do. .	1·30	12·28	37·00	49·42	1·34	71·20	4·70	1·80	0·25	8·47	12	82·38	5·44	2·08	0·29	9·81
Deoli . . .	Do. .	Do. .	2·50	13·20	36·07	48·23	1·34	68·20	4·72	1·54	0·29	9·55	10	80·89	5·60	1·83	0·34	11·34
Methani . .	Do. .	Do. .	2·48	10·60	33·40	53·52	1·60	69·02	4·90	1·67	0·30	11·03	12	79·44	5·64	1·92	0·35	12·65
Sanila . . .	9 ft. grade	Do. .	7·00	11·34	32·50	48·66	1·50	65·34	4·70	1·52	0·38	9·24	non caking.	80·50	5·79	1·87	0·44	11·40
Taposi . .	Chaukidanga.	Do. .	1·80	12·48	32·60	52·12	1·55	70·64	4·68	1·54	0·42	8·44	11	82·44	5·46	1·80	0·49	9·81
Banksimila . .	Poniati .	Do. .	5·20	10·20	36·42	48·18	1·32	69·82	4·95	1·55	0·34	7·94	11	82·53	5·85	1·83	0·40	9·39
Charanpur . .	Do. .	Do. .	4·60	7·31	34·12	53·97	1·58	71·54	5·01	1·56	0·35	9·63	10	81·20	5·69	1·77	0·40	10·94
Victoria West .	Top Ramnagar.	Barakar	1·40	12·84	23·10	62·66	2·71	71·95	4·98	1·54	0·43	6·88	16	83·89	5·77	1·80	0·50	8·04
Do. .	Bottom Ramnagar.	Do. .	1·30	11·12	27·84	59·74	2·15	73·00	4·86	1·58	0·38	7·76	12	83·37	5·55	1·80	0·48	8·85

TABLE 4.—*Results showing the relation between the caking-index and the high-temperature distillation.*

Colliery.	Seam.	Series.	Distillation at 950° C.					Analysis of gas obtd by distillation at 950°C.							B. T. U. of Gas.
			C. I.	Coke.	Tar.	Gas in Cu. ft. per ton of Coal.	$(NH_4)_2SO_4$ in lbs. per ton of Coal.	CO_2	Unsaturated Hydrocarbon.	O_2	CO	CH_4	H_2	N	
JHARIA FIELD.				Per cent.	Per cent.			Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
Jamadoba . .	18	Barakar	14	74·80	4·40	12,500	23·42	1·80	3·60	1·20	6·20	29·40	53·84	3·96	521·89
Do. . .	17	Do. .	16	76·30	4·30	12,360	23·68	2·10	3·40	1·40	6·80	28·80	53·20	4·30	512·60
Sijua . . .	16	Do. .	18	75·22	4·32	11,160	19·00	2·65	3·20	0·80	6·80	28·00	54·40	4·15	505·58
Malkera . .	15	Do. .	16	74·63	3·58	11,000	18·60	2·20	3·60	1·20	7·50	29·40	52·80	3·30	523·34
Loyabad . .	15	Do. .	14	75·65	4·46	11,220	18·80	2·40	3·20	1·20	6·50	28·60	53·80	4·30	508·38
Gopalichak . .	14	Do. .	14	75·48	4·20	11,090	19·18	2·35	3·00	0·80	6·70	29·80	53·00	4·35	514·85
Bhulanbarari .	14 Sec. A 27′ 6″.	Do. .	16	74·88	4·48	11,080	19·00	2·20	3·10	1·00	6·80	28·80	54·00	4·10	510·51
East Balgora .	14 Sec. A 12′ 7″.	Do. .	18	74·66	4·58	10,980	18·96	2·00	3·00	0·90	6·85	28·20	53·80	5·25	502·47
Bhagatdih . .	13	Do. .	15	75·80	3·60	11,080	19·63	2·40	2·60	1·00	6·60	27·40	54·40	5·60	489·34
Kustore . .	13	Do. .	17	75·84	4·08	10,782	19·02	2·00	3·20	1·40	6·20	29·90	53·40	3·90	504·54
Kirkend . .	13 Sec. A 19′ 11″.	Do. .	18	75·01	4·62	11,200	19·12	1·85	3·40	0·90	6·20	29·30	53·75	4·60	517·38
Busserya . .	12 Sec. A.	Do. .	17	75·34	4·01	11,060	18·72	2·60	2·70	1·10	7·40	27·80	54·60	3·80	518·11
Sendra-Bansjora .	12 Sec. A 14′ 0″.	Do. .	15	75·12	3·96	10,364	18·38	2·25	2·80	1·00	6·50	28·60	54·20	4·65	503·20

Chetudih . .	12	Do. .	15	74·65	4·12	10,281	18·12	2·90	2·00	1·20	6·70	28·30	55·20	5·70	471·66
Kirkend . .	12	Do. .	16	75·60	4·20	11,044	18·78	2·20	2·80	0·80	6·80	26·80	54·80	5·80	488·18
Bhagatdih . .	12	Do. .	13	76·18	3·84	11,108	18·64	2·40	2·80	0·80	6·40	28·80	54·80	4·00	507·74
Ekrakhas . .	11, bottom 10′ 8″.	Do. .	15	75·20	3·94	10,140	18·00	2·80	1·90	0·90	7·00	28·80	53·00	5·60	508·80
Katras . .	11	Do. .	16	75·46	3·82	11,124	19·20	1·60	2·80	1·10	6·60	28·50	54·20	5·20	502·66
Ena . . .	11, bottom 9′ Sec.	Do. .	17	75·84	4·00	11,472	20·10	2·00	2·60	1·00	7·20	27·30	55·30	4·60	493·07
Bhagatdih . .	11, Sec. B.	Do. .	18	75·48	3·70	11,200	19·00	2·40	2·80	0·80	6·80	29·10	53·30	4·80	506·41
Kustore . .	11	Do. .	18	76·24	3·55	10,304	18·28	1·80	3·10	1·10	6·70	29·30	52·20	5·80	509·78
Do. . .	10	Do. .	13	75·30	4·20	10,630	18·64	2·08	3·18	1·50	6·00	29·50	54·20	3·54	516·73
RANIGANJ FIELD															
Seetalpur . .	Dishergarh.	Raniganj	12	63·40	5·20	12,020	24·84	2·80	4·80	0·80	10·00	28·40	47·83	5·87	527·00
Dishergarh . .	Do. .	Do. .	13	62·90	5·40	12,200	26·46	2·70	5·20	0·95	11·20	27·80	47·05	5·10	529·73
Aldihi . . .	Do. .	Do. .	11	63·60	5·44	12,682	27·20	2·80	4·80	1·00	10·90	26·60	49·20	4·70	516·97
Parbelia . .	Do. .	Do. .	12	63·40	5·62	12,460	26·32	2·00	5·50	1·00	11·30	27·60	48·40	3·20	539·91
Deoli . . .	Do. .	Do. .	10	63·12	5·27	12,280	25·78	3·20	4·40	0·50	12·40	27·40	46·50	5·30	515·36
Methani . .	Do. .	Do. .	12	63·08	5·18	11,752	23·98	3·24	4·80	0·90	10·45	26·35	47·80	6·43	509·28
Samla . . .	9 ft. grade	Do. .	non-cak.	63·88	5·30	12,380	27·10	3·20	4·60	0·80	10·60	27·50	46·90	6·40	514·55
Taposi . .	Chaukidanga	Do. .	11	63·72	5·28	12,120	25·13	2·80	4·80	1·00	10·60	28·40	47·20	5·00	525·36
Banksimila . .	Poniati .	Do. .	11	63·34	5·60	12,426	25·72	3·10	4·50	1·10	10·60	27·60	47·75	5·15	516·07
Charanpur . .	Do. .	Do. .	10	65·18	5·20	11,800	24·96	2·75	4·60	1·20	10·30	28·60	46·80	5·75	523·56
Victoria West .	Top Ramnagar.	Barakar	16	75·60	4·05	10,240	18·28	2·40	2·90	1·00	6·60	29·10	54·60	3·40	511·16
Do. . .	Bottom Ramnagar.	Do. .	12	73·80	5·10	11,130	19·78	2·20	3·50	1·20	6·70	29·00	54·10	3·30	518·87

was resolved into oil-bitumen and solid-bitumen. Fischer and his co-workers, for the first time, explained clearly the part played by these two constituents of coal in the process of coking. The oil-bitumen is responsible for the coking and the solid-bitu-men for swelling and these two constituents together during the process of carbonisation yield a good coke. Likewise Bone and his co-workers (1924, p.33,608) also made intensive studies on the solvent action of benzene. The action of solvents on Indian coals has already been studied by the author and results obtained are in quite good agreement with those obtained by Fischer and his co-workers. It has been found by the author (Dutta Roy, 1934 p. 35) that coals of Jharia field are richer in oil-bitumen-content than those of Raniganj field and evidently this can explain the greater capacity of coking properties of the Jharia field coal.

2. SWELLING PROPERTIES.

The swelling power of coal has an important bearing on the formation of cokes. As is well known, without it, coke formation cannot occur. It is one of the main factors which control the mechanism of coking and also the operation of coke-ovens.

In consequence of the tremendous growth of the iron and steel industries, the methods for the production of metallurgical coke have advanced by leaps and bounds and there have been rapid improvements in the construction of the coke-ovens. Due to these improvements, from the earlier Bee-hive and Copper ovens, we have now the most up-to-date coke-ovens constructed by Otto, Koppers and Collins and these modern coking plants play a very important role in the efficiency of the present metallurgical industries. So it is necessary to attach due importance to the life of coking-plants and hence to the smooth running of the plant in general.

Now for a moment, if we consider the actual carbonisation process in the coke-ovens, it is found that as soon as the coal is charged by the charging holes into oven-chamber, along the walls, it is very quickly raised to the plastic stage (350°C to 450°C) and the decomposition begins from the hot wall towards the centre of the oven and naturally coke-nuts are formed at the wall. Simultaneously swelling of coal commences and as the uncoked coal prevents any expansion towards the centre of the charge, the swelling naturally exerts a pressure on the plastic mass against the wall—

the expansive pressure being a function of the degree of decomposition of coal and of the viscosity of the plastic zone. After carbonisation for about a period of four hours, the coal near the wall is converted into semi-coke and the plastic zone gradually proceeds towards the centre of the oven and the gases, as they are freed from the plastic zone, travel by the shortest path—the path being vertical to the heating wall. As the carbonisation proceeds further, the semi-coke near the wall is transformed into hard coke and the shrinkage begins. The process of carbonisation is completed in this way. The shrinkage which begins after the formation of hard coke, counteracts the expansive pressure and if the shrinkage is not sufficient to compensate this pressure, the heating wall in consequence suffers a great deal under the stresses resulting from the pressure. Thus it is evident that this expansive pressure due to the swelling of coal is detrimental to the coke-oven operation causing damage to the oven walls. But as has already been pointed out, for coke-formation swelling of coal is necessary and hence the damage to the walls of the coke-ovens will be naturally dependent upon the magnitude of swelling of coal and the shrinkage after the carbonisation. So, in recent years, the swelling of coal and the shrinkage obtained after the carbonisation have drawn the greatest consideration from the investigators on the operation of coke-ovens.

Attemps have been made to find out the expansion of the coking coals and to correlate this with the actual operation of the coke-oven chambers.

Korton (1920, p. 652), as early as 1920, proposed a laboratory method for estimating the expansive pressure by heating the coal in an iron-cylinder in an electrically heated furnace. Later on Slater (1927, p. 82), by heating coal in a silica tube sealed at one end, in a tube-oven, found out the ratio of coke-volume to that of the coal. The result thus obtained furnished merely an indication of the degree of swelling. Lambris (1928, p. 341) found out a method by which the degree of swelling as well as the capacity of coking could be measured, but the effect of the expansive pressure could not be drawn from this. Basing upon the principles of Korton, Damm (1928, p. 1078) and Hofmeister (1930, pp. 325-332, 365-372) have constructed a modified apparatus to suit their purpose in one hand and Koppers and Jenkers (1931, p. 232) have made improvements in the other hand. The essential difference of the

above modifications and improvements lies in the fact that during the process of experiments, Damm and Hofmeister keep the volume of the coal constant by varying the load while in Koppers' method the test is carried out under constant load.

In recent years important investigations have been carried out on the swelling of coal and its effect on the coking power and the process of coking, etc., by Baum and Hauser (1930, p. 1497) Pieters (1931, p. 443) and Spooner and Mott (1937, p. 96). Thus in view of the remarkable significance of the swelling power of coal, this subject, so far as it concerns the Indian coals, has naturally a great claim on the attention of the scientists and the industrialists of the country.

In the course of the studies and experiments on Indian coals of which an account is given in the following pages, the method of Koppers has been adopted because of its simplicity in design and operation and the reliability of its results.

The arrangement of Koppers' method is shown in fig. 1. 80 gms. of coal passing through $\frac{1}{25}''$ mesh are taken, covered with asbestos

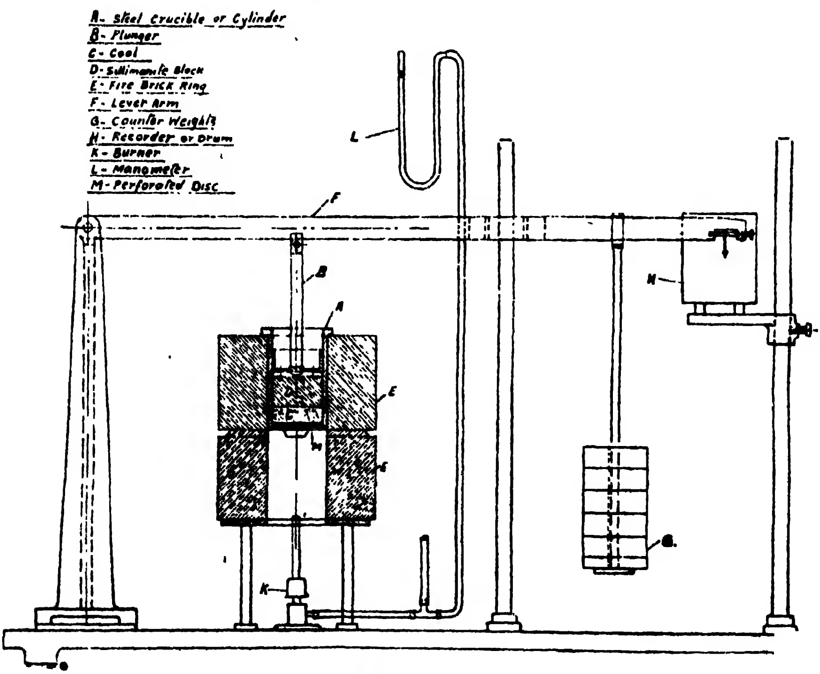

FIG. 1.

sheet ($8\frac{1}{2}'' \times 2\frac{1}{2}''$) and put into the steel-crucible, A. At the bottom of the coal-layer C, there is a perforated iron-disc M. Above the coal-layer C, a sillimanite block is fitted up and above this the plunger B. The steel cylinder, A, with the coal-layer, sillimanite block and plunger rests in a fire-brick ring E. The steel-cylinder is heated by means of a burner, K, the flame of which must not exceed 10-12 cm. G represents a constant load of 10 Kg and the expansive pressure is recorded by the recorder H.

In the following table are given the descriptions of the coal with the remarks from results arrived at from the swelling test.

TABLE 5.—RESULTS OF SWELLING TESTS ON INDIAN COALS.

Barakar Series.	Seam.	Caking-Index.	Moisture.	Ash.	V. M.	F. C.	Remarks from the swelling tests.
Jamadoba . .	17	16	1·5	10·10	28·30	60·15	Harmless.
Kustore . . .	13	17	0·80	14·00	24·12	61·08	Do.
Malkera . . .	15	16	0·90	13·80	23·60	61·70	Do.
Bhagatdih . .	11 Sec. B	18	0·80	15·08	24·42	59·70	Do.
Kirkend . . .	13 Sec. A.	18	0·80	13·42	25·20	60·58	Do.
Busserya . .	12 Sec. A.	17	1·20	14·26	24·00	60·54	Do.
Sijua . . .	16	18	0·80	18·10	24·76	56·34	Do.
Victoria West . .	Top Ramnagar.	16	1·40	12·84	23·10	62·66	Do.
Victoria West . .	Bottom Ramnagar.	12	1·30	11·12	27·84	59·74	Do.
East Balgora .	14 Sec. A.	18	0·90	16·78	24·34	58·00	Harmful.
Sendra-Bansjora .	12 Sec. A.	15	0·82	16·40	22·56	60·22	Do.
Raniganj Series.							
Seetalpur . .	Desher-garh.	12	2·00	13·27	35·40	49·33	Harmless.
Dishergarh . .	Do.	13	2·60	11·15	36·50	49·75	Do.
Aldihi . . .	Do.	11	2·00	11·82	38·20	47·98	Do.
Perbelia . . .	Do.	12	1·30	12·28	37·00	49·42	Do.
Methani . . .	Do.	12	2·48	10·60	33·40	53·52	Do.
Taposi . . .	Chowki-danga.	11	1·80	12·48	33·60	52·12	Do.
Charanpur . .	Poniati.	10	4·60	7·31	34·12	53·97	Do.
Samla . . .	9 ft. grade.	non-caking.	7·00	11·84	32·50	48·66	Do.

The curve obtained for each coal is attached (Figs. 2 and 3). The explanation of the curves obtained leads to some surprising evidences regarding the characteristics of the coals of the Barakar series (Jharia field) and those of the Raniganj series (Raniganj field).

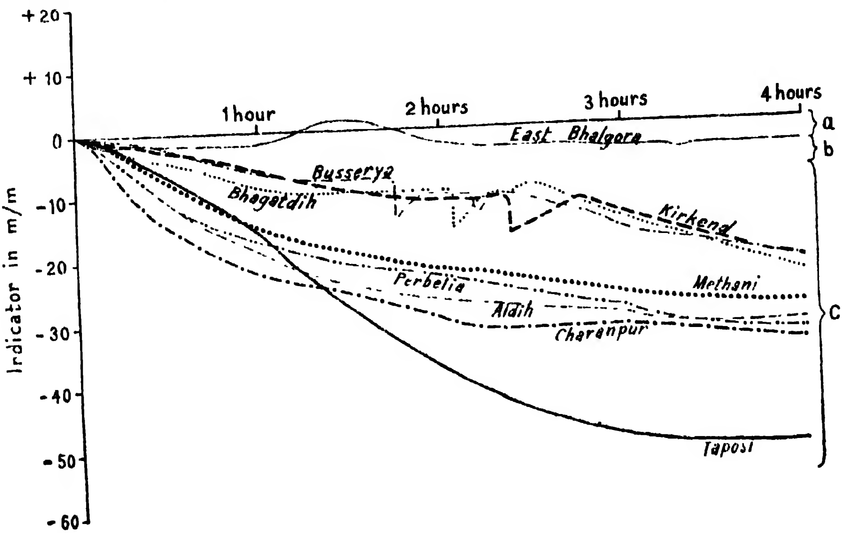

FIG. 2.

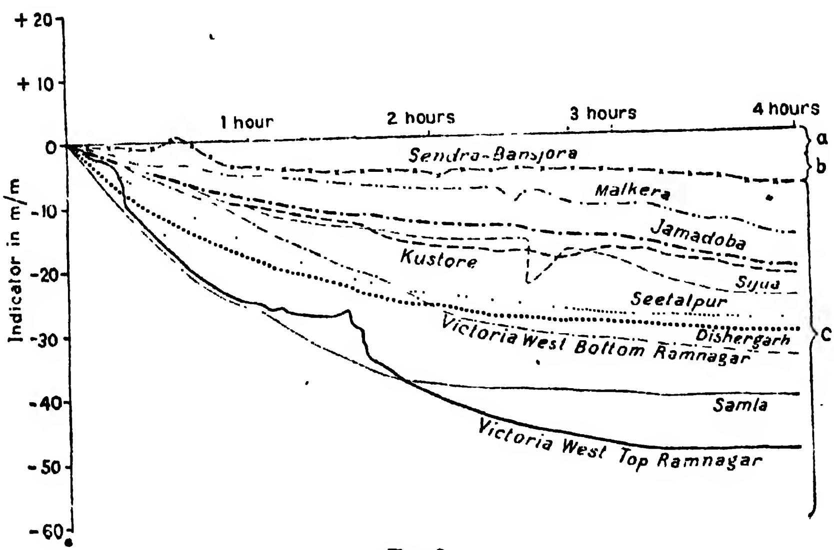

FIG. 3.

There are three divisions, namely, a, b and c in the chart and conclusion to be drawn is as follows:—When the curve of the coal under investigation rises above or below the zero line but finishes by a, the coal should be regarded as extremely dangerous. While if the curve does not rise above the zero line and finishes at b, the coal should be regarded as slightly dangerous or doubtful, but when the curve travels below the zero line and finishes at c, it is perfectly harmless. Most of the curves of the Barakar series passing below the zero line, finish just in c and therefore may be regarded as harmless. These coals can be very suitably used in the coke-ovens. The curves of the Raniganj series pass below the zero line and finish also in c and naturally they are quite harmless.

The curves of the Barakar series and the Raniganj series furnish us with some striking results. From the curves, it will be evident that coals of the Barakar series possess more swelling power than those of the Raniganj series. As has already been discussed, the swelling of coal is an integral part of the many factors in the process of coking. Coals of Barakar series are therefore superior to those of Raniganj series for the production of metallurgical coke. This conclusion coincides with the remarks observed from the study of the caking-index. But as the caking-index is a relative value—no generalisation should be made between the caking-index and the swelling power of coal.

Again the curve of Samla coal which is definitely a non-caking coal finishes in c and this is naturally to be expected from the nature of the coal.

Further, from the curves of two coals East Balgora and Sendra-Bansjora, it is evident that they are extremely dangerous. Apparently from the proximate analysis and caking-index, it can be deduced that these two coals may be used in the coke-ovens but the swelling test is definitely against their use in the coke-oven. Thus from the observation and deductions of the swelling test, the following conclusions are of importance for the operation of coke-oven.

Firstly.—Only those coking coals whose swelling curves fall under the category 'harmless' should be used in the coke-ovens.

Secondly.—Highly swelling coal should by no means be used.

Thirdly.—Clues regarding the blending of coals are available. The highly swelling coal can be mixed with non-coking coals and the mixture can easily be used in the coke-ovens.

From these considerations, broad and comprehensive ideas about the production of cokes of good quality as well as the condition for the smooth running of the coke-plant may be obtained.

3. DECOMPOSITION POINT AND THE SOFTENING POINT OF COAL.

Of the important factors that control the process of carbonisation in the coke-ovens, the effect of the caking-index and the swelling properties of coal has already been discussed. Now the study of the decomposition and softening points of coal will be of special importance because of their fundamental roles in the plastic zone. The classical researches of Foxwell (1924, pp. 122. 174, 206. 227-76, 315, 371, 1932, pp. 370), Audibert and Delmas (1927, p. 1), and Davis and Mott (1933, p. 330) have furnished fundamental data regarding the plastic zone and the formation of coke during the process of carbonisation. During the process of carbonisation, all coking coals pass through the plastic stage, where active decomposition of coal—particularly of the bitumen in the coal, takes place, the swelling begins and is accompanied by the softening of coal and transient liquefaction occurs at this stage. Hence it is during this plastic stage that the coal particles inter-mingle together, liquefy and then solidify with a new cellular structure and as the temperature rises (450-500°C) a fairly homogeneous mass 'semi-coke' is formed and at still higher temperature when the last distillation is complete, a coke of hard and rigid structure is obtained.

The strength of the cell-wall of the coke, as has been thoroughly investigated by Foxwell, is dependent upon the size and density of coal, rate of heating, the temperature of the formation and the path of travel of the principal by-products, the degree of freedom of expansion and the final temperature to which the oven is heated. So it is evident that the plastic stage is of prime importance in studying the mechanism of coke-formation. In order to have good, uniform metallurgical cokes, the coal must pass through an orderly sequence of stages and hence the studies of the decomposition and the softening points of coal which play important roles in the plastic zone are of vital necessity.

Decomposition points.

The determination of the decomposition points was carried out exactly after the well-known method of Fischer, Broche and

Strauch (1925, p. 34). The principle of the method lies in filling up a hard glass test-tube with pieces of coal and then heating it on a sand-bath. The test-tube is connected with a gas-collecting bottle filled with water saturated with NaCl and by-product gas. From the bottom of this a glass tube is connected with a measuring cylinder filled with 30 c.c. of water saturated with NaCl. As the coal is heated the air is first expelled and then, gradually with the rise of temperature, a point is reached when the coal decomposes and the first drop of Tar appears. The whole apparatus is then allowed to cool and if the actual decomposition takes place—there is a rise of water level in the measuring cylinder. This rise is of course due to the gas produced at the decomposition of coal.

In the following table are given the results.

TABLE 6.—RESULTS OF DECOMPOSITION POINTS OF INDIAN COALS.

	Seam.	Decomposition Point.
Barakar Series.—		
Kustore	11	290°C
Kustore	13	250°C
Gopalichak	14	256°C
Malkera	15	278°C
Bhagatdih	11 Sec. B	295°C
Katras	11	309°C
Loyabad	15	295°C
Sijua	16	230°C
Jamadoba	17	258°C
Kirkend	13 Sec. A	244°C
Busserya	12 Sec. A	248°C
Victoria West	Top Ramnagar	212°C
Victoria West	Bottom Ramnagar	215°C
Raniganj Series.—		
Seetalpur	Dishergarh	226°C
Dishergarh	Do.	280°C
Aldihi	Do.	295°C
Parbelia	Do.	232°C
Deolii	Do.	235°C
Methani	Do.	238°C
Taposi	Chowkidanga	240°C
Charanpur	Ponaiti	220°C
Samla	9 ft. grade	215°C

From the table it will be evident that decomposition points of coals of Barakar series are in general higher than those of the Raniganj series.

Softening point.

Various methods for the determination of softening points and hence the plastic zone have been adopted from time to time. The methods may be classified as follows:—firstly—method based on the penetration system [Damm (1928, p. 1078), Agde and Lynckner (1929, p. 86), Kattwinkel (1930, p. 329)], secondly—method based on the measurement of torsion [Davis, (1931, pp. 43-45)], thirdly—method based on the change of pressure during the plastic stage [Porter (1931, p. 613)], fourthly—method based on the measurement of change in the resistance offered by the coal layer when heated [Foxwell (1924, p. 123)], [Davidson (1930, p. 489)] and Bunte, Bruckner and Ludwig (1933, pp. 765-70). The estimation of softening point of coals was made according to the method of Jenkner and Heuser using penetration system. Full details of the apparatus are shown in fig. 4.

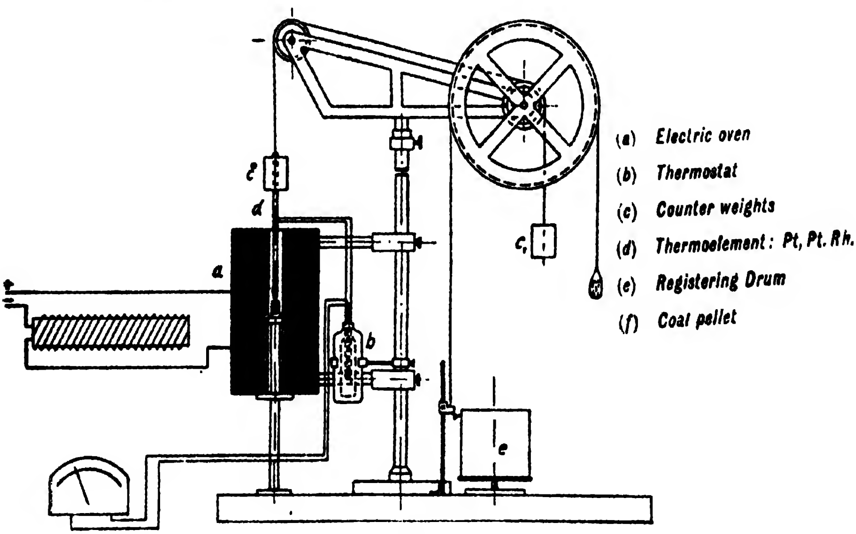

FIG. 4.

3 grams of finely powdered and air-dried coal are pressed into a brick (f) of the following dimensions (13 mm. diameter and 19 mm. height). It is then placed in the vertical electrical muffle. A pressure plunger (*c*) with the thermo-element (*d*) is just placed

upon this brick (*f*) and the muffle is heated upto 250°C in 15 to 20 minutes—then the heating is so regulated that rise of temperature should not be more than 10 degrees per minute. The softening point is registered on continuous strip of paper in drum *e*.

The results are given in the following table.

TABLE 7.—SOFTENING POINTS OF INDIAN COALS.

Barakar Series.—	Seam.	Softening point.
Kustore	11	418°C
Kustore	13	375°C
Gopalichak	14	420°C
Malkera	15	410°C
Bhagatdih	11 Sec. B	410°C
Katras	11	415°C
Loyabad	15	395°C
Sijua	16	380°C
Jamadoba	17	390°C
Kirkend	13 Sec. A	385°C
Busserya	12 Sec. A	395°C
Victoria West	Top Ramnagar	380°C
Victoria West	Bottom Ramnagar	385°C
Raniganj Series.—		
Seetalpur	Dishergarh	385°C
Dishergarh	Do.	410°C
Aldihi	Do.	395°C
Parbelia	Do.	380°C
Deoli	Do.	390°C
Methani	Do.	380°C
Toposi	Chowkidanga	395°C
Charanpur	Poniati	360°C
Samla	9 ft. grade	370°C

From the results, it will be found that the coals of the Barakar series (Jharia field) have higher softening points than those of Raniganj series (Raniganj field). The significance of the softening points will be brought out when dealing with blending of coals later on.

4. BLENDING OF COALS.

The blending of coals deserves special attention because of our limited resources of good quality coal. In the interest of the healthy growth of industries, it is our bounden duty to regulate the definitely limited assets of the country and the abnormal waste should by all means be prevented. A thorough investigation on blending of non-caking coal with Giridih coal was carried by Dr. C. S. Fox (1929, p. 294).

For metallurgical purposes, it should be the guiding pirnciple to have a coke homogeneous, rigid and strong. Therefore, in blending coals of different seams and of different qualities, the following factors of importance should be carefully considered:—

(1) Proximate analysis.
(2) Laboratory distillation results at 950°C.
(3) Caking-Index.
(4) Swelling properties.
(5) Decomposition and softening points.
(6) The constituent parts.

The function of each of these factors has already been fully discussed. The ash-content of the coal has an important bearing because of the heat-value of coke in the blast furnace; likewise the sulphur-content and phosphorus-content bear important relation to the blast-furnace practice. From proximate analysis, distillation results, caking-index, constituent parts, and softening point a clear idea of applicability of coal to the coke-ovens is obtained.

From the consideration of the above factors the following can be inferred.

(1) Coking coals with good caking-indices having similar decomposition points and softening points may produce good coke.
(2) Coking coals with high swelling properties can be mixed with other diluents such as coke-breeze or non-caking coal for the production of good cokes.
(3) Coking coals with high caking-indices and low volatile-matter content can be mixed with gas-coal for the production of good cokes.

In view of the above facts, Laboratory Studies have been made under conditions approximating to those of actual coke-oven practice.

The Results are given below.

TABLE 8.—RESULTS OF BLENDING JHARIA COALS.

Description of samples.	Per cent. Coke.	Per cent. Tar.	$(NH_4)_2SO_4$ in lbs. per ton.	Gas in cu. ft. per ton.	Quality of Coke.
(*a*) Coking-coal of Jharia field 95 per cent. + Coke-breeze 5 per cent.	74·80	3·16	18·02	10,498	Suitable for use in the blast-furnace.
(*b*) Coking-coal of Jharia field 85 per cent. + Gas coal 15 per cent.	72·30	5·18	18·88	10,888	Do.
(*c*) Coking-coal of Jharia field 85 per cent. + Non-caking coal 15 per cent.	72·80	3·88	18·20	10,512	Do.

The average results of five experiments are recorded in each case. The selection of diluents such as coke-breeze and non-caking coal will be evident from the fact that these are very easily available. The result clearly shows how the blending of coking coals with other diluents can be made use of without affecting the good quality of coke.

5. CONCLUSION.

Considering the ever-growing interest in the technical utilisation of coal and the limited resources of the coking coals of our country, the characteristics of the coking coals for the production of metallurgical cokes deserve special attention. The relation between the caking-index and the proximate analysis, ultimate analysis and high temperature distillation products, has been studied. The swelling property of coal has also been thoroughly dealt with because of its important role in the coke formation as well as its effect on the life of the coke-plant. The effect of the decomposition and softening points in the plastic-zone has likewise been discussed and from the study of all these factors, important clues regarding the formation of cokes of uniform, rigid structure by selecting different coking-coals can be ascertained. Further, important deductions for the blending of coking-coal with some diluents such as coke-breeze and

non-caking coals, etc., can also be made. Obviously, these studies will furnish desirable data for the wise and economic utilisation of the admittedly limited coal-assets of the country.

Finally I would express my thanks to Mr. E. R. Gee, for useful criticism in connection with the writing of this paper.

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THE STRATIGRAPHICAL POSITION OF THE CHERRA SANDSTONE, ASSAM. BY A. M. N. GHOSH, B.SC. (LOND.), A.R.C.S., *Geologist, Geological Survey of India.*

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Geologist, Geological Survey of India.

CONTENTS.

I. INTRODUCTION.

Prior to recent geological work in Assam, certain coal-bearing sandstones occurring beneath known Eocene strata in the Garo and the Khasi hills were regarded as Cretaceous in age. Recent investigations by Dr. C. S. Fox in the Garo hills, however, have led him to conclude that these so-called 'Cretaceous' sediments actually form a connected sequence with the overlying Eocene and are, in fact, a part of the basal Tertiary succession. The coal-bearing Cherra sandstones of Mawbchlarkar (25° 24′ : 91° 45′) in the Khasi hills were also previously correlated with the above mentioned 'Cretaceous' sandstones of the more western outcrops—in the Garo hills—but, on studying the sequence Dr. Fox came to the

conclusion that the Cherra sandstones also formed a part of the Eocene succession of Assam (Fermor, 1935, p. 82).

Scope of work.

About the beginning of the year 1935, Dr. Fox deputed me to investigate further the stratigraphical position of the Cherra sandstone as developed along the southern side of the Shillong plateau, and initiated me into the geology of the Khasi hills at Therriaghat (25° 11′ : 91° 46′) where, on the east bank of the Um Sohryngkew, the Cretaceous and Eocene beds are best developed. At his suggestion, the Cherra band was separately mapped from the fossiliferous Eocene (Nummulitic) beds above it and the fossiliferous Cretaceous below it.

Area surveyed and maps used.

The area, which is a portion of the Shillong plateau of the Khasi hills, surveyed by me during the field seasons 1935 to 1937, lies between the parallels of latitudes 25° 10′ and 25° 30′ and longitudes 91° 37′ and 92° 00′, and is covered by the one inch sheets 78 0/11, 0/12, 0/15 and 0/16. It is bounded by the Umiew river on its western and by the Um Ngot on its eastern sides respectively.

Previous workers.

Previous workers in the area included T. Oldham, whose observations on the sedimentary beds of the Khasi hills are recorded in the first volume of the memoirs of this department (Oldham, 1858, p. 99, etc.). Oldham introduced H. B. Medlicott to the area and the latter wrote a valuable account of the geology of a strip of the Shillong plateau between Shillong (25° 38′ : 91° 56′), Shella (25° 11′ : 91° 38′) and Therriaghat (Medlicott, 1869, p. 151, etc.). The eastern portion of the area was mapped by P. N. Bose in the early years of the present century. Mention may also be made of T. H. D. La Touche, who studied the coal deposits of Cherrapunji (25° 17′ : 91° 44′), Laitryngew (25° 20′ : 91° 44′) and Mawbehlarkar (La Touche, 1889, p. 169, etc., and 1880, p. 120, etc.).

Nomenclature.

Originally, the term 'Cherra series' was used by Medlicott for the infra-Nummulitic sedimentary beds of the Cherrapunji area. He left the exact horizon of demarcation between Cretaceous and Eocene in doubt but seemed to be in favour of grouping the Cherra band with the nummulitic rocks above it (Medlicott, 1865, pp. 31 and 37). Later he used the name 'Cherra sandstone' for the same beds coming above the fossiliferous Cretaceous and below the Nummulitic limestone of Cherrapunji (Medlicott, 1869, p. 169, etc.). In

the last paper he entered into a lengthy discussion for placing the Cherra band in the Cretaceous but could not produce sufficient evidence to support his views and was not in a position, therefore, to pass any opinion about its age.

In the light of present day knowledge resulting from my own field work in the Khasi hills and the works of Dr. Fox in the Garo hills and Mr. P. N. Mukerjee in the Jaintia hills, the Cretaceous appears to be more limited in distribution and extent than was previously supposed. Most of the beds mapped as Cretaceous in the Garo and the Khasi and Jaintia hills have proved to be the Cherra sandstone, which is now regarded to be Eocene.

Structural features of the Shillong plateau.

The Shillong plateau is an old land surface made of pre-Cambrian metamorphic and igneous rocks. The southern part of the plateau is occupied by basaltic lavas (Sylhet trap), which are capped by the Cretaceous and the Eocene sediments. On the plateau, the sedimentary beds have a gentle southerly dip but below Mahadek (25° 13′ : 91° 45′) and Nongwar (25° 13′ : 91° 39′) they plunge at a steep inclination towards the south. These beds thus form a monoclinal fold, the axis of which runs between E.-W. and E. S. E.-W. N. W. The crest of the fold appears to be faulted. As the area lies in a region of heavy rainfall, denudation has been very active along this zone resulting in steep escarpments, which overlook the swampy plains of Sylhet district from one end to the other.

Dr. Fox considers the structure of the Assam Range to be a warp due to the southerly thrust of the Himalaya and that the southern edge of this warp has become a monoclinal fold in the Khasi hills and an overfold and thrust fault in the Garo hills (Heron, 1937, p. 92).

II. DISTRIBUTION OF THE CRETACEOUS OF THE SHILLONG PLATEAU.

Southern foothills.

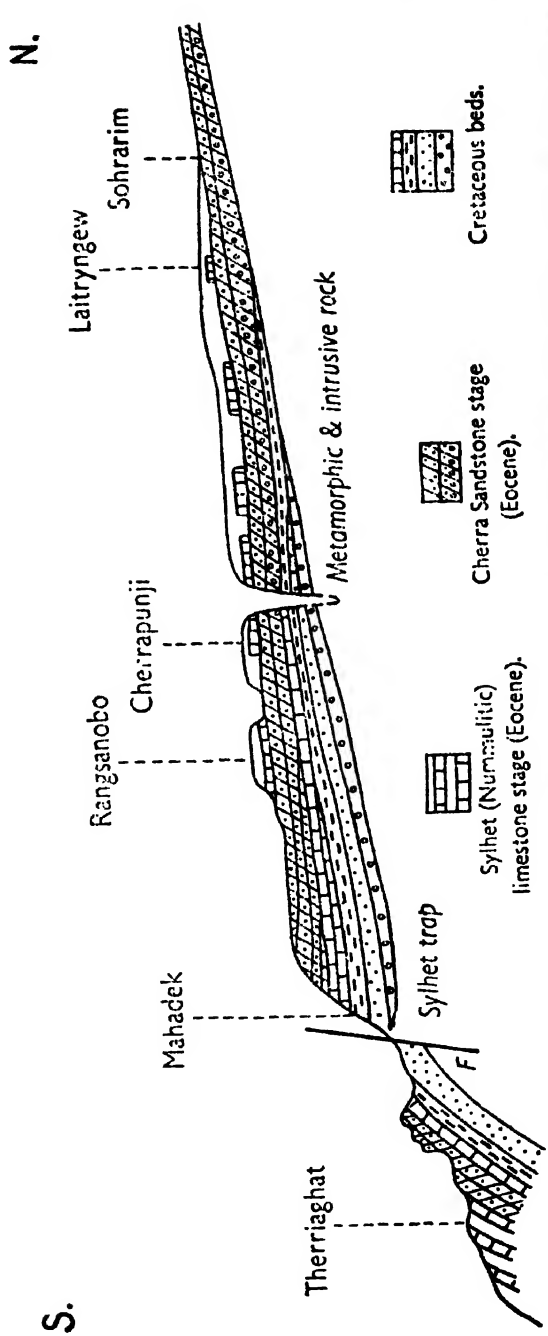
In the submontane tracts on the southern side of the Khasi hills, the Cretaceous formation is represented by arkose and massive, gritty sandstone, the upper part of which is soft, ochreous and earthy and highly fossiliferous and seems to correspond to Medlicott's Mahadek Stage (Medlicott, 1869, p. 178). The stage has a very limited north and south range and cannot be identified everywhere. It is overlain by mudstone, calcareous shale and impure earthy and sandy lime-

stone corresponding to his Langpar Stage (*op. cit.* p. 178). On the east bank of the Um Sohryngkew, the earthy limestone becomes progressively more calcareous and passes upwards into a well-bedded, massive limestone, practically devoid of fossils. Medlicott placed the limestone at the base of his Nummulitic series (*op. cit.* p. 164).

Between Shella and Therriaghat the basal part of the Cretaceous sandstone is either missing or not well exposed for study. Only in one section in the Um Niuh *nala*, E. S. E. of Nongiri (25° 12′ : 91° 48′), the base of the sandstone, near its junction with the underlying Sylhet Trap, was found to consist of fine-grained calcareous sandstone with a few pebbles in it. Between Shella and Turung (25° 11′ : 91° 51′) the sandstone, over a thousand feet thick, is fossiliferous, more particularly near the top, and has a moderate dip of 25°-30° in a southerly direction. The dip steadily lessens in amount east of Turung, and at Dawki (25° 11′ : 92° 01′) it is as much as 15°. The basal sandstone thins out to the north and east and includes bands of conglomerate, of variable thickness, at its base. These are first noticed on the spur east and south-east of Tyrna (25° 14′ : 91° 41′) and on the ridge south of Laitiam (25° 14′ : 91° 45′) and Ryngud (25° 13′ : 91° 46′).

Cherrapunji plateau.

The conglomerate assumes importance further north and in the scarp sections east and E. S. E. of Cherrapunji, is nearly 200 feet thick, where it is overlain, first by massive sandstone (400-500 feet) and then by the band of calcareous shale and earthy limestone (Langpar band), the latter coming below the Cherra band. On the road to Nongpriang (25° 17′ : 91° 45′), north of Cherrapunji, the Cretaceous conglomerate is over 100 feet thick and is overlain by sandstone, shale and sandy Langpar limestone, the latter occurring beneath conglomeratic and pebbly sandstones that form the base of the Cherra stage. In the Cherra gorge, immediately north of the main village of Cherrapunji, the Cretaceous conglomerate is 50 feet thick and in the cliff section, west of ·2405, it is less than 30 feet. The massive Cretaceous sandstone thins out very rapidly from Cherrapunji northwards, finally disappearing south-west of the waterfall ·1023. East of the same falls, about a mile and a quarter south of Laitryngew, the Cretaceous consists of the Langpar band of earthy and sandy limestone with two pebble bands, each 18″ thick, at its base. The conglomerate is well developed on the terrace, south of Laitmawsiang



Generalised diagrammatic section of the Shillong Plateau showing the distribution of the sedimentary beds. Horizontal Scale: 1 inch=1 mile, Vertical Scale: exaggerated.

(25° 18′ : 91° 45′) and can be traced as far as Laitryngew, north of which it is entirely absent. It is overlain, on this eastern side of the Cherrapunji plateau by the Cherra sandstone beginning with a pebble band at its base. It will be apparent that on the eastern side of the Laitryngew-Cherrapunji terrace there is a progressive overlapping of the lower bands of the Cretaceous by the higher ones and a general thinning of the entire succession in a northerly direction. The age of the basal conglomerate, formed in a transgressing sea, is progressively younger as we go northwards.

On the western side of the Cherrapunji plateau, overlooking the valley of the Umiew river, the Cretaceous is represented by about a couple of hundred feet of massive sandstone. The basal conglomerate and the calcareous earthy beds of the upper horizon are absent. The massive sandstone is followed above by two or three pebble bands, each eight to ten feet thick, apparently at the base of the overlying band of the Cherra sandstone. This conglomerate is different from the lower conglomerate so well developed on the eastern side of the plateau and seems to belong to the Cherra stage. The sheer cliff formed by the Cretaceous sandstone thins out further north and disappears under the upper cliff of Cherra sandstone, south-east of ·4430, S. S. W. of Ryngimawsaw (25° 20′ : 91° 41′). Looking westwards along the cliff face below Mawsynram (25° 18′ : 91° 35′) the lower sandstone band of the Cretaceous can be seen thinning in a northerly direction.

South-east Khasi hills.

Along the south-eastern side of the Khasi hills, the Cretaceous beds are not so well developed and the upper beds are frequently denuded away. The massive sandstone shows gradual thinning in the Um Krem, the Um Lyngdoi and the Um Jashar valleys. The sandstone with a pebble band at its base in the valley of the Piyan Gang near Dawki is considerably reduced in thickness. Between Dawki and Mawshun (25° 14′ : 91° 58′) the sandstone thins rapidly. The basal conglomerate, at first, is associated with massive sandstone supporting the calcareous beds of the upper band but in a northerly direction the sandstone passes into sandy and earthy limestones carrying echinoids and *Ostrea.* Pebbly sandstones and conglomerate, less than 50 feet in thickness, are exposed along the motor road between Phlangpontung (25° 15′ : 91° 57′) and Phlangudiak (25° 17′ : 91° 55′), where they are succeeded by ash coloured earthy and sandy limestone of the upper band. In the river beds east and north-

east of Mawlyndun (25° 16′ : 91° 54′), the conglomerate is associated with the same earthy beds.

Outliers of the Cretaceous conglomerate, from which the overburden of the sandy limestone has been entirely removed by denudation, occur in the neighbourhood of the villages of Pynter (25° 16′ : 91° 58′) and Mawpran (25° 18′ : 91° 57′), and continue beyond the E.-W. *nala*, immediately north of Wahtyrsaw (25° 18′ : 91° 55′). In the bed of the *nala*, the conglomerate is over six feet thick and is overlain by Cherra sandstone. Pebble bands in soft sandy beds are present, near their junction with metamorphic rocks, on the footpaths descending to Myllad (25° 19′ : 91° 56′) and Mynrieng (25° 19′ : 91° 53′), E. N. E. and north-west respectively of Pynursla (25° 18′ : 91° 54′) but they cannot be identified further north. It seems that the true Cretaceous beds do not extend north of Khyrwet (25° 19′ : 91° 54′) where, in the cliff section west of the village, the conglomerate, so well developed in the stream beds and on the motor road E. S. E. and south-east of Pynursla, is represented by a few scattered pebbles.

It will now be apparent that the Langpar band of calcareous shale and earthy and sandy limestone is more consistent and widespread than the lower sandstone and it progressively overlaps the latter shorewards in a northerly direction. On the Cherrapunji and the Thang Jnat plateaux it is possible to fix the northern boundary of the Cretaceous within a mile south of the parallel of latitude 25° 20′. It is about this latitude that the calcareous earthy beds of the Cretaceous disappear. It may be observed in passing that R. W. Palmer noticed a break, within the Cretaceous rocks of the western Khasi hills, roughly along the parallel of latitude 25° 22′ (Palmer, 1924, p. 158). It is difficult to say whether the Cretaceous sea transgressed this line from the southern side or not, but evidence in favour of any such possible transgression within the Cretaceous period is wanting.

III. GENERAL FEATURES AND DISTRIBUTION OF THE CHERRA SANDSTONE.

Before dealing with the distribution of the Cherra sandstone, which overlies the fossiliferous Cretaceous and occurs below the Eocene Nummulitic (Sylhet) limestone, a short description of its lithological and other features may be given. The Cherra sandstone * is

Lithology of the Cherra sandstone.

essentially a shallow water marine deposit (Heron, 1939, p. 59). There is a possibility that the clay bands it contains may have been deposited under fluviatile and lacustrine conditions. False-bedding of the sandstone is very common. This suggests that the sandstone was subjected to strong current action while it was being deposited. There is no constancy either of the texture, composition or colour of the sandstones which vary from place to place. The sandstone is fine- to coarse-grained in texture and is sometimes very hard and compact and makes good building stone. At many places, however, it is extremely friable and powdery. It is felspathic at places and highly quartzose at others. Between Therriaghat and Mawblang (25° 14′ : 91° 44′) there are evidences of the sandstone having been formed by the leaching out of the calcium carbonate of a sandy limestone and secondary quartz has been noticed in the sandstone formed as a result of the replacement of the lime of the sandy limestone by silica. The sandstone is frequently pitted, very likely due to the falling out of nodules of pyrites, which have been noticed at many places. Efflorescence of sulphur is quite common. As a rule the sandstone is light cream and buff coloured but it also presents a variety of other colours and carries bands of variegated sandy shale and lumpy mottled clay. Sometimes the sandstone carries bands of carbonaceous shale and at places it is definitely carbonaceous. In the Mawsmai Falls, a thin band of coal was noticed in the sandstone and at Mawbehlarkar the Cherra band carries a workable seam of coal. Indistinct plant remains are noticed at places in the sandstone otherwise it is practically devoid of fossils, which have only recently been found at one place in the Khasi hills (Heron, 1939, p. 60).

Cherra stage of Therriaghat.

At the foot of the Cherrapunji plateau, in the neighbourhood of Therriaghat, the Cherra stage is represented by massive limestone passing upwards through a sandy limestone into a fine grained, yellowish sandstone showing ill-preserved plant remains in all some 400 feet thick. On the east bank of the Um Sohryngkew, the lower part of the limestone is earthy and grades downwards into the impure, earthy limestone and calcareous shale (Langpar band) of the Cretaceous. Medlicott placed the massive limestone band at the base of his Nummulitic series and its position above the Langpar band agrees with this classification (Medlicott, 1869, p. 164). The overlying band of the plant bearing sandstone is succeeded by

the foraminiferal limestone belonging to the lowest band of the Sylhet limestone (Heron, 1936, p. 85).

Although the Cherra stage is present on the hills south and E. S. E. of Nongiri, it is not well represented in the area between Therriaghat and Shella, where the country is very broken. The partial absence of the beds of the stage may be in part due to local slips and to the underground solution and removal of the limestones and sandstones and thus causing the upper beds to sag and collapse. On the terrace, west of Mahadek, the Cherra beds have been removed by denudation but they are present as outliers on the ridges on which are situated the villages of Nongwar and Laitkynsew (25° 13′ : 91° 40′).

Cherra beds of the Cherrapunji plateau.

The Cherra band is best developed on the Cherrapunji plateau, where the succession consists of 300-400 feet of sandstones with interbedded shales. The sandstones are almost horizontal and when inclined have a very gentle dip towards the south. They can be traced as a continuous band for about ten miles in a north-south direction between Mawblang on the south and Lad Mawphlang (25° 22′ : 91° 45′) on the north. South-east of Cherrapunji as well as in the Mawsmai Falls, the beds are pebbly at certain horizons, more especially in the lower part of the stage, which rests on the earthy and sandy limestone belonging to the Langpar band of the Cretaceous. At the cliff section at Rangsanobo (25° 15′ : 91° 44′), south of Cherrapunji, the Cherra sandstone is conformably overlain by Nummulitic limestone, no sign of any physical break being visible between the two sets of beds.

Infra-Nummulitic sandy limestone, similar to the Cherra limestone at Therriaghat, was noticed in a stream section, west of the path from Mahadek to Mawsmai (25° 14′ : 91° 44′). Here also the calcareous earthy beds of the Cretaceous pass upwards into an impure, earthy limestone with subordinate dark grey, carbonaceous shales and bands of a bluish limestone. Higher up the band the limestone becomes sandy and grades into a calcareous sandstone first and then into a pure sandstone as at Therriaghat. This is the sandstone, which builds up the southern edge of the Cherrapunji plateau. The above-mentioned limestone cannot be traced northwards around the cliff sections of the Cherrapunji plateau, excepting on the descent to Nongstein (25° 17′ : 91° 39′) where an algal lime-

stone, some 200 feet thick, was noticed in corresponding position below the Cherra sandstone about 350 feet from the top of the descent. The limestone rests on a band of sandy clay with a conglomerate about ten feet thick at its base. The succession is underlain by massive Cretaceous sandstone. While the absence of the limestone may possibly be due to a substitution of the calcareous facies of the submontane tracts on the south by an arenaceous facies of the Cherra followed by the Nummulitic (Sylhet) limestone beds on the north, the possibility of the former existence of the Cherra limestone cannot be overlooked, since the presence of large swallow holes in the Cherra sandstone, west and south-west of the motor road at Mawblang, suggests the occurrence of a soluble band as limestone below the sandstone. Similar swallow holes are present in the Cherra sandstone on the southern side of the Thang Jnat plateau near the villages of Wahmawsiang (25° 14′ : 91° 51′), Nongphlang (25° 14′ : 91° 54′) Mawkinber (25° 15′ : 91° 54′) and elsewhere.

Along the footpath descending to Nongriat (25° 15′ : 91° 40′) W. S. W. of Cherrapunji, the Cherra band becomes pebbly and conglomeratic near the base, resting on the sandy Langpar limestone. Similar pebbly and conglomeratic sandstone bands, in corresponding position, are present in the Mawsmai Falls as well as on the eastern side of the Cherrapunji terrace and can be traced along the cliff sections at Falls ·1023 to Laitmawsiang-Mawlyndier (25° 19′ : 91° 46′) terrace resting on Cretaceous beds. The pebble band becomes the basal conglomerate of the Cherra stage, east of Laitryngew, where it rests upon a thin sandy band, possibly belonging to the Cretaceous. East of Sohrarim (25° 21′ : 91° 44′) there are two conglomerates within the Cherra sandstone stage. The upper one appearing some 200 feet from the top of the plateau and is separated from the basal conglomerate, about 150 feet thick, by alternating bands of fine grained and pebbly purplish and cream coloured sandstones. On the western side of the Cherrapunji plateau, the Cherra conglomerate appears much further south, where it occurs at variable depths at the base of the Cherra stage. On the descent to Umblai (25° 17′ : 91° 39′) the pebbles are embedded in a calcareous matrix, which yielded a solitary shark's tooth belonging to the genus *Odontaspis* and a few crushed bivalve shells. The conglomerate on the western side of the plateau increases in thickness in a northerly direction and is well developed on the

terraces overlooking the valleys of the Um Iong, Um Jaut and Umiew rivers, west and north of Sohrarim and more than one such band is present in the sandstone. The conglomerates with their overburden of sandstone rapidly thin out north of Sohrarim, the basal band on the eastern side uniting with its counterpart on the west just north of Lad Mawphlang and the two are met with as one discontinuous band along the Laitsopliah (25° 23′ : 91° 46′) ridge in a barrier of metamorphic conglomerate and quartzite of pre-Cambrian age to Mawbehlarkar, where the Cherra sandstone carries a coal seam and a band of coal shale. A plant impression, similar to that noticed in the plant-bearing sandstone at the Therriaghat section, was found in the carbonaceous shale of Mawbehlarkar. Thin outliers of the sandstone with the underlying conglomerates are present as far north as Steplakrai (25° 25′ : 91° 45′) and also on the hills near Lum Didom, Lum Kyrphai, Umsawmat (25° 24′ : 91° 42′), Lyngiong (25° 25′ : 91° 42′), etc., further north of which the band is very thin and at places consists of loose pebbles, the cover of the sandstone having been eroded away. On the hilltop east of the river Um Sohra, outliers of the Cherra sandstone and conglomerate occur at Mawrap (25° 23′ : 91° 47′) and Mawthawtin (25° 22′ : 91° 46′). The exposure east of Diengsaw (25° 21′ : 91° 46′) includes highly carbonaceous and pyritic sandstone near the base.

Distribution in eastern Khasi hills.

The Cherra sandstone stage is not well developed on the eastern side of the Khasi hills, having been considerably removed by denudation from the southern edge of the Umniuh (25° 12′ : 91° 50′) plateau, only a small patch occurring on the northern side. Between Ringer (25° 14′ : 91° 54′) and Sohlait (25° 14′ : 91° 52′), the sandstone supports dislodged blocks of a sandy limestone, very likely the lowest band of the Sylhet limestone. The Cherra sandstone continues northwards under a thin band of lower Sylhet limestone supporting sandstone with coal at Thang Jnat (25° 17′ : 91° 54′) and Lyngkerdem (25° 21′ : 91° 54′) and ends near Ryngian (25° 22′ : 91° 53′), where it has a thin pebble band at its base. The Cherra sandstone country, south of the Thang Jnat plateau, is very rugged and broken and consists of swallow holes and tumbled masses of the dislodged sandstone.

Outliers of the Cherra sandstone are present at several places further north, the most conspicuous of them occurring south of

Mawlyngngot (25° 24′ : 91° 56′), where the stage is represented by a conglomerate, about 70 feet thick, overlain by a false-bedded sandstone of similar thickness. Here and there on the plateau, east of Laitlyngkot (25° 27′ : 91° 50′) may be found thin skins of pebbly sandstones resting on kaolinised granite and east of Phansawrut (25° 28′ : 91° 53′), an outlier of the sandstone rests on a zone of lithomarge.

Behaviour of the Cherra conglomerate.

It will be noticed that the Cherra conglomerate is extremely variable in thickness and disposition. Although to some extent an uneven land surface may account for its inconsistencies, it is easy to visualise that in early Cherra times the sea bed was oscillating and regression and transgression of the sea was a common feature, resulting in similar phenomena. In the case of marine deposits, when the overlap is of a compound regressive-transgressive nature, the basal conglomerate will rise in the geological scale seawards in the case of the former and shorewards in the case of the latter. This would account for the presence of more than one band of conglomerate in different horizons of the Cherra stage, until more stable marine conditions were finally established.

Northern extension of the Cherra sea.

The Cherra sea must have continued north of the axis of the present Khasi hills plateau, as is indicated by the widespread distribution of isolated outliers of the stage. Such outliers frequently carry thin bands of lithomarge pointing to the condition of weathering in a moist tropical climate that preceded the deposition of these beds. A narrow outlier with a thin conglomerate at its base occurs at Laitdom (25° 36′ : 91° 40′) but, more important, is the faulted outlier at Nongkhrong (25° 37′ : 91° 21′). The latter contains marine fossils of which the forms *Arca*, *Corbula* and *Leda* could be recognised and some imperfect casts of gastropods and a coral (? *Trochocyathus*). The sandstone, in which these fossils occur, is only a few feet thick, and is underlain by gneisses and abuts against laterite on its eastern side (Heron, 1939, p. 59). Dr. Fox considers the beds at the Um' Rileng coalfield, seven miles north-west of Shillong to correspond to the Cherra sandstone stage (Heron, 1937, pp. 85-86).

IV. SYLHET LIMESTONE STAGE.

The Cherra sandstone stage is succeeded upwards by the Sylhet (Nummulitic) limestone stage, which consists of limestone, sandstone,

shale and coal. The most complete succession of the stage is on the east bank of the Um Sohryngkew, where it is represented by three highly fossiliferous limestone bands separated by sandstones of variable thicknesses. The uppermost limestone is mostly built of large and medium sized *Nummulite* and *Assilina*. Between Therriaghat and Shella the band is overlain at places by an earthy limestone and marl entirely made of *Discocyclina*. The middle limestone is teeming with *Alveolina*, while the third or basal limestone shows sections of gastropods and tiny foraminifera. The sandstone below the *Alveolina* limestone carries coal south of Maolong (25° 13′ : 91° 42′). On the southern side of the Cherrapunji plateau, the nummulitic beds above the Cherra sandstone have been removed by denudation. In the Rangsanobo cliff, the stage consists of a sandy limestone supporting a sandstone with a coal seam. The limestone,[1] which appears to correspond to the basal band of the Sylhet limestone at Therriaghat, overlies the Cherra sandstone in normal stratigraphical sequence and no sign of any physical break is visible between the two. In comparison with the development at Therriaghat, the limestone is considerably attenuated at Rangsanobo and rapidly thins out northwards. It is present at several places in the scarp sections between Cherrapunji and Laitryngew and is last seen near the villages of Mawkma (25° 20′ : 91° 43′) and Laitlyndop (25° 20′ : 91° 42′). The diminution in the thickness of the limestone northwards is, however, accompanied by a corresponding increase in the thickness of the overburden of sandstone, which in places, when the limestone is absent, passes imperceptibly downwards into the Cherra sandstone. The passage in such cases is so gradual that it is difficult to delineate the boundary between the two stages owing to the lithological similarity of the Cherra and the Nummulitic (Sylhet) sandstones. There is no evidence on the Shillong plateau of the beds of the Sylhet (Nummulitic) limestone stage north of a line joining Lyngkerdem and Sohrarim.

Similarity of Cherra and Nummulitic (Sylhet) sandstones.

The difficulty of differentiating the Cherra from the Nummulitic (Sylhet) sandstones on the Cherrapunji plateau was admitted by Medlicott (1869, p. 168). The two sandstones have features in common which at once suggest their being parts of the same group and

[1] It should be noted that the forms *Assilina* and *Alveolina* found in the two upper limestones at Therriaghat have not been recorded anywhere on the Cherrapunji plateau. The Cherrapunji coal occurs in the same stratigraphical horizon as the coal at Maolong.

different from the fossiliferous Cretaceous sandstone. The sheer, wall-like scarp caused by the massive and rudely bedded Cretaceous sandstone can be easily distinguished from the overlying cliff of Cherra and Nummulitic (Sylhet) sandstones, with their numerous planes of bedding and intercalated shale and clay. The feature thus provided by these sandstones is very characteristic and apparent all along the cliffs overlooking the deep gorges that dissect the plateau. Further, the bands of lumpy, mottled clay and shale present in the Cherra and the Nummulitic (Sylhet) beds are absent from the Cretaceous strata.

V. STRATIGRAPHICAL POSITION AND POSSIBLE AGE OF THE CHERRA SANDSTONE.

Unsatisfactory palaeontological evidence.

It is the common rule to determine the age of any sedimentary deposit by means of the fossils it contains. The Cherra sandstone, however, is singularly lacking in decent fossils. The few organic remains that the stage has yielded are rather disappointing as they are badly preserved and do not admit of proper study. One has, therefore, to look for other evidences collected in the field. In fixing the stratigraphical position of the Cherra stage, the lithological similarity of its sandstone and shale components with those of the Nummulitic (Sylhet) stage is a point in favour of regarding the two stages as members of the same group and separating the former from the Cretaceous. It has already been stated that on the Cherrapunji plateau no sign of discordance is noticeable between the Nummulitic (Sylhet) limestone and the Cherra sandstone.

Conformable sequence of Cherra and Nummulitic (Sylhet) beds.

From Sohrarim northwards only Cherra beds can be traced and the northern outliers may be regarded to represent the higher beds of the same stage of the southern side. Nowhere in the Khasi hills, has the Nummulitic (Sylhet) limestone been found to overlap the Cherra stage and the recent surveys in the Garo and the Jaintia hills have disclosed the same phenomenon. Wherever the Nummulitic (Sylhet) limestone occurs it is supported on a base of Cherra sandstone, suggesting the intimate association of the two.

Evidence of overlap.

In the Khasi hills the Cherra stage has overlapped the Cretaceous in a northerly direction. According to Dr. Fox and Mr. Mukerjee, the overlap has also taken place in the direction of the strike of the beds, west-

wards in the Garo hills and eastwards in the Jaintia hills, suggesting the overlap to be widespread and regional. That the overlap took place after a period of readjustments of the land and sea at the end of Langpar time, is well illustrated in the cliff sections in the Cherrapunji plateau. This is the feature which Medlicott noticed in the cliff face below the main road south-west of the Mawsmai Falls (*op. cit.*, p. 169) and which he thought to be a local feature due to false-bedding, naming it as 'pseudo-unconformability'. In this section the Cherra sandstone is noticed to overlap, in a northerly direction, a sandy limestone, apparently the highest band of the Langpar stage of the Cretaceous. A similar feature is noticeable about the same horizon in the cliff face looking westwards from Mawmluh (25° 15′ : 91° 42′) and also from Pamduloi (25° 18′ : 91° 41′) towards Mawsynram. The overlap is best illustrated in the cliff sections, east of the motor road between Cherrapunji and Laitryngew. Looking towards the west from the Falls ·1023, one can observe the earthy limestone band of the Langpar stage making an angle of 10°-12° with the overlying band of Cherra sandstone, which is almost horizontal in this cliff. On a clear day the same feature is noticeable on a much larger scale looking from Pynursla towards Cherrapunji.

This unconformable overlap, caused by the eustatic movements of the sea, indicates a definite break in the continuity of deposition in the Khasi hills during the Cretaceous-Eocene interval. It is apparent that, following the deposition of the Langpar stage of the Cretaceous, the sea retreated southwards in that area and a gentle dip was imposed on the emerged Cretaceous sediments. In the early Eocene, the sea again transgressed northwards resulting in the deposition of the littoral Cherra stage and the overlying variable strata of the Nummulitic (Sylhet) sequence. From time to time during the Eocene, deltaic conditions prevailed locally. Drifted vegetation brought from inland became buried in the sand and mud and was ultimately converted to coal, the larger accumulations forming definite seams intercalated in the sandstones of the Cherra and the Sylhet limestone stages.

Evidence of the Cherra conglomerate.

The hiatus and the pause in sedimentation preceding Cherra times are further indicated by the occurrence of several bands of conglomerate near and at the base of the Cherra stage and by the absence of the Langpar band from the western end of the Cherrapunji

plateau, where the massive Cretaceous sandstone is also attenuated. It is not unlikely that the attenuation of the Cretaceous beds may represent a local break in sedimentation in Langpar times which became a general feature of the plateau later on. While the Langpar stage was being deposited on the eastern side of the plateau, an upward tilt of the sea bed on the western side would bring the Cretaceous strata within the reach of the agencies of denudation and so thin them down by erosion.

Passage beds at Therriaghat,

The evidences cited above establish a hiatus between the Cherra stage and the fossiliferous Cretaceous beds on the Cherrapunji plateau. In the submontane tract near Therriaghat, however, there is a passage from the undoubted Cretaceous into the massive limestone, which is homotaxial with the Cherra stage of the plateau. It seems, therefore, that while away in the open sea in the Mahadek-Therriaghat region uninterrupted sedimentation was taking place, the present Khasi hills plateau from Mawsmai northwards formed a land surface after the close of Langpar times and remained so till it was submerged again in Cherra times. It is necessary, therefore, to separate the Cherra stage of the Cherrapunji plateau from the Cretaceous, to regard it as the basal stage of Medlicott's Nummulitic series and to place it in the Eocene.

Discussion on the probable age of the Cherra stage.

Although the Cherra stage can be separated from the Cretaceous in the plateau, there is not sufficient palæontological evidence to decide the exact age of the stage. The fossils collected and identified by Mr. Mukerjee from the Cherra sandstone of the Jaintia hills are (bivalves) *Macrocallista virgata* d'Orb., *Cardium brongniarti* d'Arch., *Cyprina* cf. *transversa* d'Arch., *Cardita sp.*, *Meiocardia sp.*, and a gastropod, *Natica sp.* The fossils merely indicate Lower Tertiary age but do not allow of a more precise definition.

Evidence of laterite.

The association of the basal portions of the Cherra stage with laterite and kaolin in various parts of the Garo, Khasi and Jaintia hills is an additional evidence for placing the stage in the base of the Eocene, because laterite is known to occur at many places at the base of the Eocene of North West India. Dr. Fox's suggestions, that there was a main laterite-forming period in Northern India in early Eocene times and that the kaolinisation of the gneisses of the Garo hills occurred about the same time (Heron, 1936, p. 34), appear to agree with the available data in Assam.

The points that deserve special attention in this connection are the ages of the Langpar stage of the Cretaceous and the Sylhet stage of the Eocene, since the Cherra sandstone stage intervenes between the two former sets of beds. The fossils that were examined by Spengler are from the sandy Mahadek beds of the Cretaceous and indicate Upper Senonian age, 'that is the Upper Campanian according to Grossouvre or to the Mæstrichtian according to Haug' (Spengler, 1923, p. 65). The overlying band of calcareous shale and earthy limestone (Langpar stage) have yielded casts of numerous gastropod such as: *Xenophora, Cinula, Strigetella, Apphorais, Cyprea, Turritella,* (bivalve) *Corbula,* (echinoid) *Hemiaster sp.,* (scaphoda) *Dentalium sp.,* (ammonite) *Pachydiscus sp.,* ? *Baculites sp.,* and three nautiloids, of which a fragmentary piece shows a close resemblance to *Hercoglossa danicus,* a typical Danian form, while the other two bear similar affinities to the same. Coming as it does on a higher stratigraphical horizon than the Mahadek band, the Langpar stage can, therefore, be placed in a position corresponding to the Danian.

Age of the Langpar stage.

As regards the Sylhet limestone stage, it is possible to fix the age of its upper part only, since the different species of *Nummulite,* which have been identified are restricted to the upper limestone. They belong to the upper Laki or Lower Khirthar of the Eocene (Pascoe, 1925, p. 40). The *Alveolina*-limestone of the middle portion of the stage can conveniently be placed in the Laki, but the age of the lowest band of foraminiferal limestone remains undetermined.

Age of the Sylhet limestone stage.

It has already been stated that between the lowest band of the Sylhet limestone stage and the Langpar band, the equivalent of the Cherra sandstone is represented, on the east bank of the Um Sohryngkew near Therriaghat, by a plant bearing sandstone underlain by a feebly fossiliferous '*massive*' limestone, which carries thin bands of shale near its base and passes into the underlying impure earthy Langpar limestone. The hiatus at the top of the Cretaceous on the Cherrapunji plateau, is, therefore, represented by a continuous series of deposits in the submontane tracts, east of Therriaghat. Although the latter are apparently conformable on the Langpar band on the one hand and to the overlying Sylhet limestone stage on the other, there is a big faunal break, since none

Evidence of faunal break.

of the Cretaceous forms survive in the '*massive*' limestone that intervenes, feebly fossiliferous though it may be. It is reasonable to assume that this limestone must have been laid down at a time characterised by such changes in climatic and physical conditions as were hostile to the survival of the specialised fauna of the Cretaceous sea, resulting either in their migration to places where ecological conditions were favouable or the wholesale extinction of these forms. This may be the reason why the '*massive*' limestone is so sparing in organic remains, although they occur in profusion in the limestone bands of the Laki and Danian above and below it respectively. It is evident that Paleocene time was ushered by a cataclysmal change in Assam which explains the impoverishment of fauna in the lower portions of these beds.

Conclusion.

It, therefore, appears reasonable to conclude that these poorly fossiliferous, '*massive*' limestones of Therriaghat together with the overlying plant-bearing sandstones are of lower Eocene (Ranikot) age, bridging the gap between the fossiliferous upper Cretaceous and the Laki. To the north of Therriaghat on the Khasi hills plateau, this Ranikot phase is represented in part by a time interval—evidenced in places by the unconformity that is found at the base of the Cherra sandstone stage—and later by the strata of the Cherra stage itself.

Parallel conditions appear to have prevailed in north-west India where, in Sind, the break between the Mesozoic and the Tertiary is slight or is absent altogether, whilst further north in the Punjab the time interval separating the Mesozoic and the Paleocene is considerable, and is often marked by a prominent unconformity.

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LIST OF PLATES.

MGIPC—M—VIII-1-4—21-11-40—720.

Plate 1.

FIG 1 CRETACEOUS SANDSTONES DIPPING SOUTH AT 35
WEST BANK OF THE UM SOHRYNG KEW.

A M. N. Ghosh, Photos. *G. S I. Calcutta.*

FIG. 2. GENTLY DIPPING CRETACEOUS SANDSTONES.
EAST BANK OF THE UM NGOT,

Records. Vol. LXXV. Professional Paper, No. 4.

Plate 2.

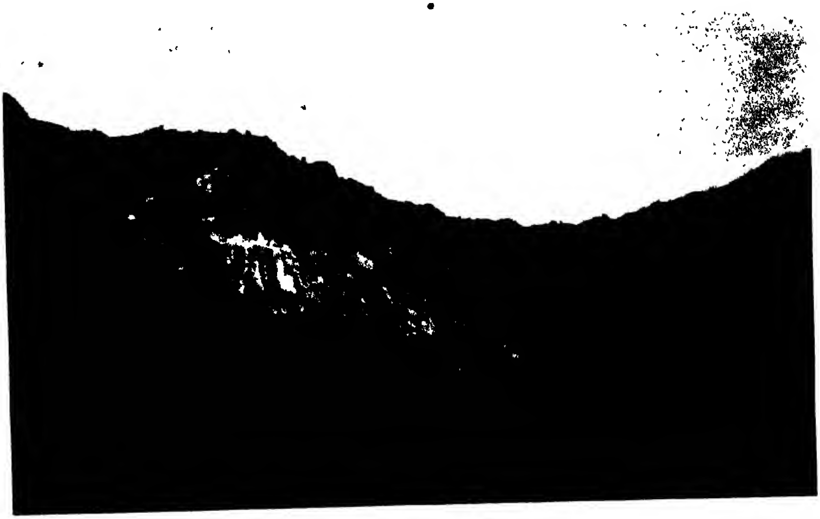

FIG. 1. UNCONFORMITY BETWEEN LANGPAR LIMESTONE (LOWER CLIFF) AND CHERRA AND NUMMULITIC (SYLHET) SANDSTONES (UPPER CLIFF), NEAR FALLS .1023, SOUTH OF LAITRYNGEW.

A. M. N. Ghosh. Photos. G. S I. Calcutta.

FIG. 2. CONGLOMERATIC CHERRA SANDSTONE (WITHIN 200 FEET FROM

Plate 3.

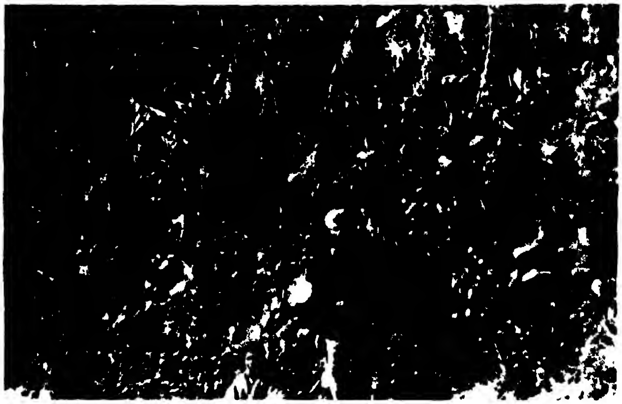

FIG. 1. CHERRA CONGLOMERATE, EASTERN SIDE OF THE RIDGE, SOUTH OF MAWLYNGNGOT.

A. M. N. Ghosh, Photos. *G. S I. Calcutta.*

FIG. 2. CRETACEOUS CONGLOMERATE, (OVER 500 FEET FROM TOP OF CLIFF), EAST OF CIRCUIT HOUSE, CHERRAPUNJI.

FIG. 3. MASSIVE CRETACEOUS SANDSTONE CLIFF, OVERLAIN BY BEDDED CHERRA SANDSTONE, FOOTPATH TO NONGSTEIN.

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Rai Sahib N. K. GHOSH.

Geological Survey Office, Library and Museum, 27, Chowringhee Road (Indian Museum Buildings), Calcutta.

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PERMIAN FUSULINES FROM THE KARAKORAM.
BY CARL O. DUNBAR.

Published by order of the Government of India

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PERMIAN FUSULINES FROM THE KARAKORAM.

BY CARL O. DUNBAR.

Through the kindness of the Geological Survey of India, I recently received for examination a small piece of fusuline-bearing limestone collected from Calcareous Sandstones in the Shaksgam valley between the Karakoram and Aghil ranges (collection K41/484).*

The specimen contains two large, elongate species of *Parafusulina*. Although both are new, they represent a stage of fusuline evolution of unmistakable Permian age. It is believed that they are somewhat younger than the zone of *Parafusulina kattaensis* (Schwager) in the Lower Productus limestone of the Salt Range. They are definitely younger than the Artinsk series of the U. S. S. R. and probably fall in the horizon of the upper part of the Leonard or the Word, formation of Texas.

Parafusulina shiptoni Dunbar. sp. nov.

Plate I, figures 1-7.

Description.—A subcylindrical species of 6 to 7 volutions, attaining a length of 16 to 17 mm. and a diameter of 2·3 to 2·6 mm. The lateral slopes taper slightly toward the sharply rounded poles.

The prolocula range in size from about 100 to about 225 microns and have a very thin wall. The whorls are low and the radial

* The fossils were discovered and collected in 1937 by Mr. J. B. Auden of the Geological Survey of India while he was on an expedition in the Karakoram led by Mr. E. Shipton, a well-known mountaineer.

expansion gradual. The shell elongates very rapidly, the form ratio being near 5·0 in the third volution and over 6·0 at maturity.

The spiral wall is only 15 to 20 microns thick in the first whorl, increasing slowly to a maximum of 70 to 90 microns in the sixth. It is distinctly alveolar and is almost entirely formed of the keriotheca, the tectum being very thin.

The septa are unusual in that the basal margin of each is regularly and deeply folded whereas the upper half or more is almost plane. As a result, the septal loops appear low and rounded in spite of the fact that the folding has reached the parafusulinid stage and low cuniculi are clearly shown in tangential slices (Plate 1, figures 4 and 5). Septal pores are sparsely scattered and rather obscure in the specimens studied.

The tunnel angle is wide, increasing from 25°-34° in the first volution to a maximum of 50° or 60° in the fifth and sixth, but there is considerable variation as shown in the table below. There are no chomata at any stage of growth. One of the most distinctive features is the massive axial filling that begins a short distance on each side of the middle and extends with increasing diameter almost to the ends of the shell.

Table of measurements.

(In millimeters)

	Half length				Radius vector				Form ratio			
	#1	2	3	4	#1	2	3	4	#1	2	3	4
0	·093	·10	·10	·116	·093	·10	·10	·108	—	—	—	—
1	·36	·57	·50	·57	14	·20	·21	·257	2·6	2·8	2·4	2·2
2	70	1·23	1·16	1·40	·23	·32	·36	·33	3·4	4·0	3·2	4·2
3	1·6	1·85	2·4	2·40	·33	·40	·50	·46	5·0	4·6	4·8	5·2
4	2·8	3·00	3·8	3·9	·48	·57	·66	·66	5·8	5·8	5·8	6·0
5	4·1	4·45	6·0	5·5	·64	·76	·89	·91	6·4	6·0	6·7	6·0
6	5·8	6·86	8·0	7·2	·91	1·09	1·19	1·20	6·4	6·3	6·6	6·0
7	8·3	...	...	...	1·27	...	...	...	...	...	...	...

	Tunnel angle				Wall thickness				Septal count	
	#1	2	3	4	#1	2	3	4	#5	6
1	27°	29°	30°	34°	·015	·020	?	·020	15	15
2	35°	40°	36°	35°	·022	·028	·045	·250	16	16
3	33°	43°	35°	33°	·030	·035	·055	·050	20	22
4	38°	40°	50°	?	·045	?	·055	·055	23	24
5	37°	41°	58°	50°	·055	·060	·065	·070	24	27
6	55°	62°	...	...	·070	...	·080	·090	30	32
7	44°	...	...	...	...	...	...	·085	29?	...

Specimens 1, 2, 5 and 6 are illustrated on plate I as figures 1, 3, 6 and 7.

Discussion.—In shape and in its abnormally low septal folds, this species shows considerable resemblance to "*Fusulina*" *wanneri* Schubert of the Permian of Timor. However, that species is somewhat smaller and relatively thicker than this, having a normal length of 10 to 13 mm. and a diameter of 2·2 to 2·5 mm. It has an axial filling similar in distribution to that of our species but far less massive. There is a pronounced difference also in the form of the overlapping ends of the whorls as seen in axial sections. Schubert's single figure of a slice of rock, showing one good axial section and fragments of others, does not indicate clearly the presence of cuniculi but one specimen at the lower right corner of his figure suggests their presence.

Some of the axial sections figured by Colani (1924, pl. 14) as *Fusulina longissima* Möller resemble our species very closely. Her material was from the Permian of Indo-China and appears to represent more than one species, neither of which can be identified with Möller's form from Russia. Figures 4 and 26 of plate 14 of Colani's monograph indicate a subcylindrical species shaped much like ours, having a similar axial filling, similar low septal loops, and a thin-walled proloculum. Moreover, the volutions overlap at the ends much as they do in our species. But Colani's species has a length of only 10 mm. at 6 or 7 volutions while ours has a length of 16 mm. Moreover, the axial filling is much more massive in our species. It is not clear from Colani's figures whether cuniculi are present and the septal evolution may be less advanced than it is in our species.

There is considerable resemblance to *Schwagerina linearis* Dunbar and Skinner from the Wolfcamp formation of Texas, but that is a smaller species and is in a less advanced stage of septal evolution, having no cuniculi. There is also a superficial resemblance to *Polydiexodina persica* Kahler, but in that form the septal folds are high and supplementary tunnels are present.

The large size and especially the stage of septal evolution displayed by *Parafusulina shiptoni* sp. nov. indicates beyond any doubt a Permian age. No species as large or as advanced as this has been found in the Artinsk division of the Permian in Russia. The new species is probably somewhat younger than *Parafusulina kattaensis* (Schwager), the common one in the Lower Productus limestone of

the Salt Range. Its stage of evolution indicates an equivalence to the upper part of the Leonard formation or to the Word formation of Texas.

Occurrence.—Three miles south of Durbin Jangal, Shaksgam valley, at about 13700 feet (36°2′ : 76°40′). Geological Survey of India Type Nos. 17268—17274.

Parafusulina sp. A.

Plate I, figure 8.

Associated with many specimens of *P. shiptoni*, we discovered a single specimen of entirely different form, of which a perfect axial section was secured. Although it was embedded in solid matrix with *P. shiptoni*, no other fragments of this stout species could be found. Reluctant to base a species on a single section, however good, we merely illustrate and describe this specimen without a name.

As shown by figure 8 of plate I, it is a stout, subcylindrical shell having blunt ends and no inflation at the middle. Consisting of $5\frac{1}{2}$ volutions, it has a diameter of about 3·2 mm. and a length of about 13·7 mm. The shape changes gradually during growth, being elongate-fusiform with pointed ends in the early whorls.

The proloculum has a diameter of 290 microns, is subspherical, and has a moderately thin wall. The equatorial expansion is gradual and the coiling rather loose. The spiral wall has a thickness of ·070 mm. in the second volution, ·070 mm. in the third, ·085 mm. in the fourth and ·100 mm. in the fifth. It is distinctly alveolar. As in the associated *P. shiptoni*, the septal folds are rather strong and regular, but are chiefly limited to the lower margin of each septum. The tunnel is wide, its angle measuring 42°, 45°, 55°, 58° and 61°, respectively, in the 5 volutions. Axial filling by epitheca is limited to small, disconnected spots near the axis in the ends of successive whorls.

This species has no close resemblance to the associated *P. shiptoni* and appears to be undescribed. It resembles *Schwagerina setum* Dunbar and Skinner, which occurs high in the Bone Spring limestone (*i.e.*, Upper Leonard) of West Texas, but differs therefrom in numerous details. For example, its septal folds are lower, its expansion is more rapid, it is larger in corresponding volutions,

its form ratio is less, and its tunnel angle is considerably greater than that of the Texas shell. It is presumed that the septal evolution has advanced to the stage of *Parafusulina* in the Indian species but, unfortunately, this cannot be proved by the axial section.

Occurrence.--Same as *Parafusulina shiptoni* sp. nov.

PLATE I.

Parafusulina shiptoni Dunbar, sp. nov.................. p. 1

FIGS. 1-3. Axial sections (×10) of three cotypes. G. S. I. Type Nos. 17268—17270.

FIGS. 4, 5. Tangential slices (×10) of two cotypes, showing the evidence of cuniculi (*c*). G. S. I. Type Nos. 17271 and 17272.

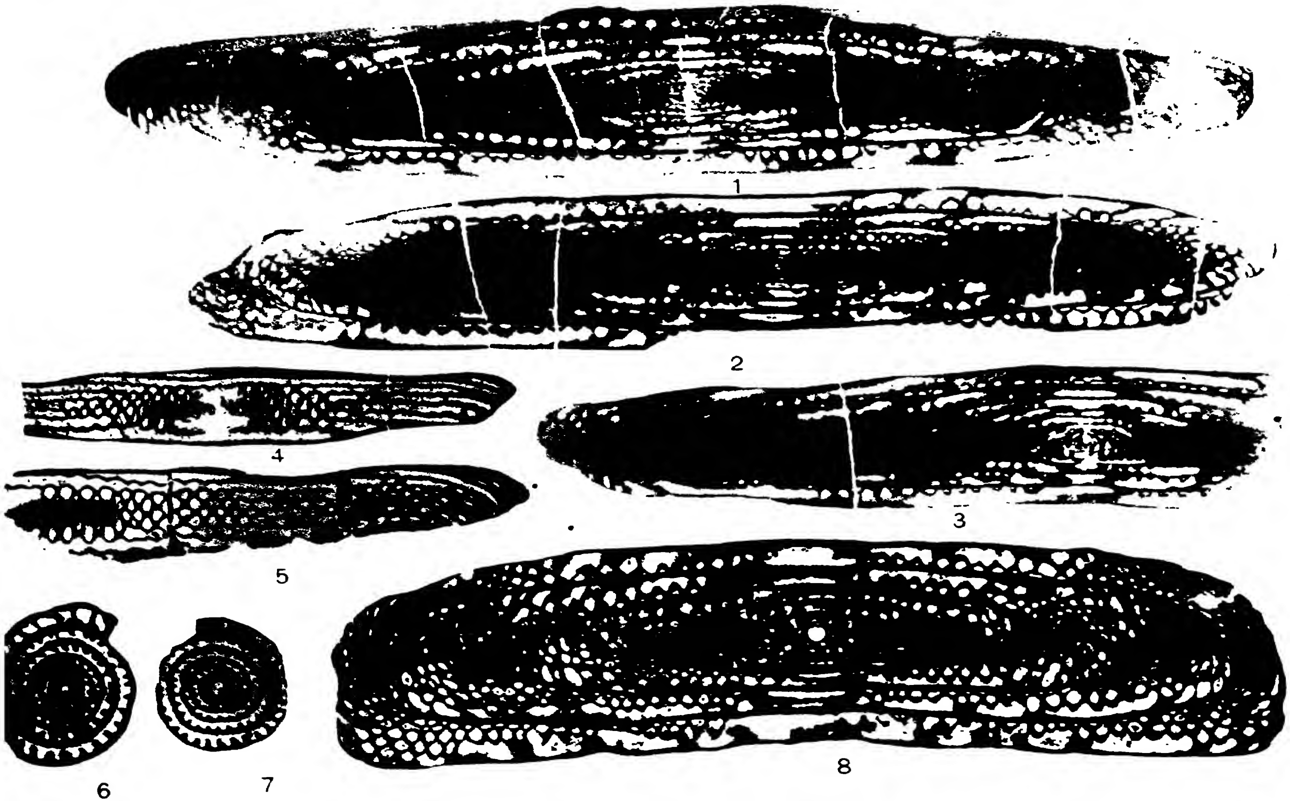
FIGS. 6, 7. Sagittal sections (×10) of two cotypes. G. S. I. Type Nos. 17273 and 17274.

Parafusulina sp. A...K41/484b........................ p. 4

FIG. 8. Axial section (×10) of the unique specimen.

MGIPC—M—VIII-1-5—10-9-40—700.

Plate 1



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B. K. DUTTA ROY, M.Sc. (Dac.), Dr. Ing. (Hanover).

Assistant Geologists.

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Did the Indobrahm or Siwalik River exist?

By M. S. Krishnan, M.A., Ph.D., A. R. C. S., F.N.I., and N. K. N. Aiyengar, M.A., *Geological Survey of India.*

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BY M. S. KRISHNAN, M.A., PH.D., A. R. C. S., F.N.I., AND N. K. N. AIYENGAR, M.A., *Geological Survey of India*.

CONTENTS.

I. INTRODUCTION.

Between the Himalayan ranges on the north and the great Indus-Ganges-Brahmaputra plains on the south there is a series of deposits of Middle and Upper Tertiary age forming the foot-hill zone of the Himalaya. These consist of an older Murree series of Lower to Middle Miocene age and a younger Siwalik system (or series) of Upper Miocene to Lower Pleistocene age. The rocks

of the Siwalik system are found all along the Himalayan foot-hills from the north-easternmost corner of Assam on the east to Jammu and Kashmir State on the west and thence along the hills of the N.-W. F. P., Baluchistan and Sind down to Karachi. Though it is conceded that this thick series of Siwalik rocks was of fluviatile origin, yet the exact mode of deposition is rather obscure.

R. D. Oldham was of the opinion that the Siwalik beds were deposited subaerially by streams and rivers and also that the whole drainage of Northern India at that time had only one outlet to the sea, probably in Sind. In 1919, two geologists of the Geological Survey of India—Dr. (now Sir) E. H. Pascoe (**30**) and Dr. Guy E. Pilgrim (**35**)—each published a paper in which the hypothesis was put forward that the Siwaliks were laid down by a single large river flowing from the north-east corner of Assam along the foot of the Himalayas to Kashmir and then southwards to the Arabian sea. To this river Pascoe gave the name 'Indobrahm', for he thought that the modern Indus and the Brahmaputra are the dismembered parts of this original river. Dr. Pilgrim, who had extensive knowledge of the Siwalik strata, had come to much the same conclusions quite independently, and gave it the name 'Siwalik River' basing his observations particularly on the distribution of the boulder-conglomerates of the Siwalik system.

In recent years much geological work has been done on the Tertiaries of the Punjab and Assam by the members of the Geological Survey of India and other geologists. It appears therefore worth while reviewing the results of these investigations in connection with the question of the Siwalik sedimentation, and particularly with the ideas advanced by Pascoe and Pilgrim.

II. PASCOE'S HYPOTHESIS.

At the outset let us state the arguments put forward by Pascoe in support of his Indobrahm river. The main points of Pascoe's hypothesis are (**30**, p. 138):—

"i. That in Eocene times a gulf extended from Sind northwards as far as Afghanistan, and thence curved eastwards and south-eastwards through Kohat and the Punjab to the neighbourhood of Naini Tal.

ii. That this gulf gave place to a great river, the headwaters of which consisted of the portion of the Brahmaputra flowing through Assam. This river flowed westwards and north-westwards along the foot of the Himalaya as far as North-West Punjab, where it turned southwards along a line not very different from that of the modern Indus, and emptied itself into the Arabian sea. In other words, the Assam Brahmaputra was once the headwaters of the Indus.

iii. That two separate rivers or two branches of the same river debouching into the Bay of Bengal, cut back and beheaded this old Indus, the eastern capturing the Assam portion to form the Brahmaputra, and the western capturing gradually piece by piece the portion that intervenes between Assam and the present Jamna.

iv. That in the meantime this old river was being still further reduced by the piecemeal capture of the portion lying between the Jamna and the Jhilam by its own tributaries, the Jhilam, the Chenab, the Ravi, the Beas, the Sutlej and the Ghaggar.

v. That the Attock part of the present Indus was a tributary of this old river, which at a comparatively early period cut its way back into Kashmir, where it captured the upper waters of a large river that flowed north-westwards, and either found its way into the Oxus or curved south-westwards into Eastern Afghanistan."

Further, he has explained his ideas regarding Siwalik drainage and sedimentation in the following manner (**30**, p. 145) :—

"(1) A marine gulf originally occupied most of the same line, and during the silting process the oil and coal of this region were produced and gypsum was deposited ; this hydrocarbon, coal, and gypsum belt follows the Nummulitic outcrop from Kumaon to the Mekran coast. Such a filled-up gulf is naturally followed by a river—for instance, the Burma gulf by the Irrawaddi, or the Mesopotamian gulf by the Tigris and Euphrates,—which would be pushed farther towards the centre of the peninsula by the persistent movement.

(2) The supposition that the Siwalik deposits were laid down as enormous talus-fans by the mountain-streams which issued from the plains, has always been difficult to accept in view of the great thickness of the deposits—for they average over 16,000 feet—and their great extent. An almost unbroken belt of these beds can be traced, usually in great thickness, from Assam to the Soan valley and thence to Baluchistan, bounded externally by continuous mountain country consisting, where known, of igneous and very ancient rocks, with or without an intervening belt of Murree rocks. It seems far more reasonable to deduce a single river rather than a number of transverse streams. The mountain streams, in any case, must have had an outlet to the sea in one direction or the other, and must have joined a main river in the plains.

(3) There are no grounds for assuming that the northwards-flowing drainage of the old Gondwana continent was reversed in Siwalik times. In fact, the depression of the trough would have invigorated this drainage, which, it is highly probable, persisted to this day. It seems almost certain, therefore, that this northerly drainage must have met the southernly Himalayan drainage in a large river flowing either south-eastwards or north-westwards. Since the Siwalik outcrop is not continuous to the sea south-eastwards, but is practically continuous north-westwards and subsequently southwards along the line of an old gulf, it seems reasonable to assume that the river followed this direction.

(4) This Siwalik belt is succeeded on the side towards the peninsula, and remote from the mountain-building, by a similar and even thicker belt of recent river-deposits, to be mentioned later.

(5) Many of the streams draining the Himalaya have north-westward pointing V's in their course where they cross the Tertiary foot hills, or where they enter the plain. These are thought to indicate, according to Dr. Pilgrim's suggestion, a former north-westward-flowing main river, of which these streams were tributaries (see below).

(6) The similarity of the river-fauna in the Ganges and in the Indus points to a connection best explained on the assumption of a large main river uniting what are now the Ganges and the Indus basins (see below).

(7) The similarity in nature and strike between the Shillong Plateau and the northern region of the Indian Peninsula makes it probable that they represent what was once a continuous feature, the flank of a long river valley. It is this continuity of the physiographical and geological features along this line from Assam to the Punjab that is so striking. There is a continuous regular mountain-arc of ancient rocks on the north; there is a parallel upland of similar ancient rocks on the south, continuous beneath the presumably shallow gap between the Rajmahal and Garo Hills; between this mountain-arc and the upland is a continuous outcrop of Alluvium of great maximum thickness, occupying a continuous trough, and succeeding what there is no reason to doubt, is a continuous Tertiary river deposit. The sub-alluvial barrier deduced north-north-east of Delhi interrupted neither the continuity of the Siwalik deposits nor that of the Alluvium. There is no rock barrier in the plains at the present day between the basins of the Indus and the Ganges, the watershed being a scarcely perceptible one.

(8) The two hypotheses of single westward-flowing river flanking the Himalayas throughout their length, one on the Indian side and one on the Tibetan side, mutually support each other, and are strengthened by the curious parallelism between the histories of these two hydrographic lines (see below)."

III. THE PRESENT FEATURES OF NORTHERN INDIA.*

A modern topographical map of India will show that the Ganges has a general eastward course, and its tributaries both from the Himalaya and from the peninsula meet it after flowing more or less in an easterly direction. The Brahmaputra (Tsang-po) has a long easterly course in Tibet, but cuts across the Himalaya in a southward direction and then flows westward and southward to join the Ganges. The Indus flows first north-westwards, then turning southwards (and south-westwards) empties itself into the Arabian sea. All its tributaries have a general south-westerly course except those which come from the west. The divide between the Indus and the Ganges basins, which passes through Delhi and Ambala, is barely 900 feet above sea level. This divide is a continuation of the Aravalli range traversing Rajputana, and geological work has shown that its influence is felt in the Himalayan region along its north-easterly continuation (**2**, pp. 157-158).

In order to understand the evolution of the Siwalik drainage it is necessary to trace the geological history of the Himalayas and the contiguous plains from the Eocene period onwards.

IV. THE EOCENE PERIOD.

Marine Eocene rocks are found extending from Sind through Quetta, the Sulaiman Hills, Dera Ismail Khan, Bannu and Kohat on the north-west, then through Hazara to Kashmir. Patches of the same formation are found in south-west Rajputana, Cutch and Kathiawar, to near Broach. It would appear that the last-mentioned patches are continuous, underneath the recent deposits of the Indus, with the main formations of Sind, Baluchistan and Salt Range. This Arabian gulf, there is reason to believe, was connected with the Tethys sea of the Himalaya and the Tibetan region (**7**, p. 415). The apparent absence of the nummulitic strata between Jammu and the Simla region can reasonably be explained by an overlap. As suggested by various geologists, the Eocene sea must have extended right across Sind-Rajputana-Punjab, while a narrow

An extension of the Arabian Sea.

* Regarding the Himalayan rivers *see* Burrard, Sir S. G., Hayden, H. H. and Heron, A. M.—A sketch of the Geography and Geology of the Himalaya mountains and Tibet, Delhi, 1933.

arm of this gulf possibly extended from Jammu to near Lansdowne. No marine Eocene rocks have been found in the Lesser Himalaya east of the last-mentioned place, which it is interesting to note, marks the north-easterly extension of one of the eastern ridges of the Aravalli range. The outcrops of Nummulitic strata near Naini Tal and Lansdowne are of small thickness (**23**, p. 19) and distinctly of shallow water facies so that they evidently mark the proximity of the shore line.

Influence of the Aravalli Barrier.

At the period we are considering, the Aravalli range should have been of greater extent and elevation than they are now, and should have played an important part as a great topographical and hydrographic feature. Rivers would have flowed from these ranges westward as well as eastward, while the peninsular uplands of Bundelkhand and Central India should have been the sources of rivers flowing northwards to join the Tethys or one of its arms.

Nepal-Assam Himalaya.

The evidence available is not very clear regarding the geography of the Sub-Himalayan region between Naini Tal and the Assam Himalaya. No Eocene rocks have yet been found in this tract and this may be taken as indicating the existence of a land surface here in early Tertiary time, with the Tethys only a short distance to the north. This land should have formed the northern border of the Indian peninsula.

Assam Plateau.

It is only in the southern part of the Shillong plateau that we find any evidence of an Eocene sea, but this belongs to the Bay of Bengal region. It has been shown by Dr. C. S. Fox that the present configuration of the east coast of India took shape in late Mesozoic times with only slight invasions and retreats in later periods. The Upper Cretaceous transgression of this sea left a series of deposits including the early Tertiary ones in the southern part of the Shillong plateau and the Arakan region.

V. THE FIRST PHASE OF HIMALAYAN UPHEAVAL.

We shall now turn our attention to the changes that took place when the Himalayas began to be formed. In the Upper Eocene times the Tethyan basin was lifted up, corrugated and thrust towards the south, producing an extensive new topography. The advancing mass found the Indian peninsula a comparatively rigid

barrier, and between the two units was probably formed a furrow or 'fore-deep' the evidence for which is however not clear in the area east of Dehra Dun. As a result of these movements, the Eocene gulf of the Punjab seems to have become smaller and broken up, for there are no deposits of the age immediately following this (*i.e.*, the first phase of upheaval) in the Naini Tal area.

The Aravalli ridges lying at right angles to the direction of movement of the Himalayas should have offered great resistence to folding. But it is probable that the mighty forces of orogeny may have slightly buckled even these opposing ribs.

VI. THE CHHARAT—MURREE PERIOD.

The geological records are fairly clear in the Indus basin. After the first upheaval there came into existence a longitudinal trough in which were laid down firstly the Chharat and then the Murree sediments. This trough appears to have been much shallower and broader on the west than on the east, for it is believed that the Himalayas were elevated to a greater degree in the east than in the west during the upheaval. As a consequence, the trough in the east should have been deep and narrow and any sediments deposited in it might conceivably have been covered over by later ones.

Indus basin.

The sediments deposited in the region of north-western Punjab after the first upheaval are known by the name of Chharat series. They contain both marine fossils and remains of terrestrial (marshy land) animals. These basins of deposition were still more or less marine in nature. It is not clear to what extent sediments were derived from the newly formed Himalàya to the north and from the Peninsular area to the south and south-east.

Punjab: the Chharats.

The Subathu beds of the Simla foot-hills are generally correlated with the Chharats. They comprise grey and red gypseous shales together with some nummulitic limestone lenticles, while at their base there is a bed of pisolitic limonite. There appears to be no definite information as to the exact age of the Nummulitic beds of Naini Tal region but they are likely to be of the same age as the Subathus.

Simla foot-hills: Subathus.

The Murree sediments (Miocene) were laid down in basins whose waters were gradually becoming brackish from the previous saline state (**23**, p. 113). The greater part of the sediments seems to have been derived from the peninsula, since they contain much iron derived from the disintegration and oxidation of ancient rocks. The great thickness of these rocks near Murree may be due to this area being a large lake or lagoon which gradually deepened and kept pace with the sedimentation. The presence in them of plants (like *Sabal major*) and numerous mammalian remains points to the gradual establishment of fresh-water conditions.

Punjab region: Murrees.

As regards the distribution of the Murree sediments it is to be noted that they are represented by the Dagshai beds of the Simla region which are regarded as the equivalents of the Murrees. They comprise bright red to purple nodular clays and fine grained sandstone. Middlemiss states that the gradual passage of the Subathu clays into the sandstone of the Dagshai and Kasauli stages has also been accepted as proving a gradual change from marine conditions to those of fresh-water. They terminate at the Aravalli barrier quite a good distance west of the easternmost nummulitic outcrops, while the Murrees extend westwards into the North-West Frontier Province and then southwards.

Simla Region.

VII. SECOND PHASE OF THE HIMALAYAN UPHEAVAL.

The second phase of mountain building, which was of Middle Miocene age, seems to have been of great magnitude for, after this, the Tethys was obliterated from the Himalayan region. This created a very well recognisable furrow all along and just south of the Himalayas about which we shall speak presently. But at the same time were established land conditions in the Himalayas and also a definite southerly drainage.

In the eastern (Ganges-Brahmaputra) drainage basin this furrow is recognised by the presence of Siwalik rocks. *It is not known* whether this region was connected with the Bay of Bengal after the first upheaval. But there seems to be every probability that the second upheaval broke down the barrier across the Rajmahal-Garo region.

In the Middle Miocene we notice evidence of the extension of the Bay of Bengal, for deposits of this age are seen at various places on the East Coast as far as Orissa and also on the southern border of the Shillong Plateau. The Cuddalore Sandstone, the Rajahmundry Sandstone and the Miocene beds of Baripada in Mayurbhanj constitute the evidence of this transgression.

Miocene transgression of Bay of Bengal.

As regards the extension of the Bay of Bengal into the Ganges valley, Pascoe thought that there was no such connection in the Miocene or even in the Pliocene, and advocated the formation of this gap through the Rajmahal ridge in Pleistocene times without assigning any convincing reason in support.

If, however, we look into the structure of the Shillong Plateau, we notice that it has been subjected to movements from two sides, one from the north by which overthrust faults have been developed and one from the east producing extensive block-faulting, the blocks being bounded by north-to-south faults. The portion of the old ridge between the Rajmahal hills and the Garo hills appears to have been depressed during the period, probably by the downward block faulting or by buckling, because of the thrust from the east. The cause envisaged here is quite adequate for producing the gap in question, and it should be pointed out that no such convincing tectonic cause is available at a later age to explain the formation of the depression. Moreover, if the gap were of post-Pliocene age as thought by Pascoe, the topography of the region would be decidedly less mature than it is, as pointed out by C. E. N. Bromehead in the discussion of Pascoe's paper before the Geological Society of London. Bromehead has stated (*Quart. Journ. Geol. Soc.*, **75**, p. 156, 1919):—

Age of the Garo-Rajmahal depression.

"If the lower course of the Ganges and the Brahmaputra was also of recent date, and due to the cutting-through of a hard ridge joining the Indian Peninsula to the Assam Hills, one would expect a gorge similar to that of the Indus instead of the broad open valley which, on the map, had all the appearance of mature age."

VIII. SIWALIK SEDIMENTATION.

The Siwalik sediments, ranging in age from Middle Miocene to Lower Pleistocene, were deposited in the furrow formed after the second upheaval. The lowest beds (Kamlials) are hard brown *sandstones, pseudo-conglomerates* and shales. The beds above (*Chinjis*) are medium

Punjab region.

grained grey coloured sandstones with abundant bright red shales. The Nahans, which are the equivalents of the Chinjis in the Kashmir-Simla region, are highly arenaceous and comprise indurated brown and grey sandstones and red shales.

The Middle Siwaliks in the Punjab region consist of thick-bedded massive grey sandstones, clay beds becoming more prominent towards the top. In the Upper Siwaliks, the lower beds are coarse grained sandstones which give place to beds of shales and of conglomerates further up. The topmost bed is the Boulder Conglomerate consisting of large boulders in a fine-grained silty matrix.

Kumaon-Garhwal.

In the Garhwal region, the Nahans attain a thickness of 6,000 ft. according to Middlemiss. The Middle Siwaliks of the Kumaon-Garhwal tract is termed 'sand-rock', being micaceous sandstones with some ferruginous matter, and also some brown to red clays. They are 7,000-8,000 feet thick here, according to Middlemiss. The sandstones contain grains of jasper and amethystine quartz and magnetite, felspar, etc. The presence of these, and especially of jasper grains, might indicate that the source was at least partly the crystalline rocks of the Peninsula to the south. The Upper Siwaliks of the Garhwal region are said to contain pebbles derived from Himalayan rocks—Nahan sandstones, granite, trap, quartzite and vein quartz,—and also bands of clay and loamy matter. Middlemiss assigned a thickness of 5,000 feet to the Upper Siwaliks of the Kumaon region.

Bhutan.

The Siwaliks are known to extend eastwards along the foot hills of Nepal and Bhutan. In the latter region (**31**, p. 23) they overlie Gondwana or older rocks. The outcrop, where examined, was six miles wide and showed a fairly full succession. The lower beds consist of blue clays with fine grained argillaceous sandstone and indurated clays. Overlying these are 'pepper and salt' sandstones containing a few pebbles. Above these are conglomerate beds containing small pebbles at first, the size of the pebbles gradually becoming larger up to the size of a man's head. Some of the Siwalik sandstones are highly ferruginous.

There are some breaks in the continuity of Siwalik outcrops in this region, especially one for a length of about 40 miles to the east of the Jaldoka river (**20**, p. 48).

Aka Hills.

In the Aka Hills La Touche (**18**, p. 122) found Siwaliks forming a conspicuous band and overlying the Gondwanas. They are composed of sandstones, partly quartzitic, and conglomerates and carbonaceous shales.

Daphla Hills.

The Daphla hills and the Subansiri valley (**19**, p. 194) also show similar Siwalik formations which rise abruptly from the plains to form hills 2,000 to 3,000 feet high. They consist of sandstones and conglomerates, the former containing silicified wood.

Abor Hills.

In the Abor Hills tract the Siwaliks attain a good development and comprise various types of sandstones and conglomerates. The 'pepper and salt' sandstones found here are probably of Middle Siwalik age. Dr. Coggin Brown (**5**, p. 237) states that the Siwaliks are continuous with those found in the Subansiri region and further west.

Patkoi-Naga-Arakan region.

It is known that the Siwalik rocks continue across the Brahmaputra. But there is apparently a break in the outcrop in the Sadiya frontier tract. To the south of Sadiya, Upper Tertiary rocks equivalent to the Siwaliks appear in great force and are known by the name of Tipam series (Lower and Middle Siwalik) and Dihing series (Upper Siwalik). According to P. Evans (**9**) :—

"The Tipam series is known over a vast area, being found as far south-west as the Arakan coast of Burma. It extends through Tripura (Hill Tippera) to the Surma valley, is found in a few synclinal areas in the North Cachar Hills, is a prominent feature of the outer ranges of the Naga Hills, stretches thence nearly continuously to the Frontier tracts in the north-east of the Assam Valley and probably continues into the Hukong valley of Burma. *It is almost certain that the rocks of this series occur in the first range of the Himalayas and extend beneath the alluvium of the upper part of the Brahmaputra valley........*" (Italics ours).

IX. GENERAL DISCUSSION.

Composition of the Siwaliks.

In each division there is a preponderance of sandstones in the lower portion and abundance of clays and shales in the upper, except in the Upper Siwaliks in which there are intercalations of conglomerates and the upper beds are coarser than the lower. As a general rule the Siwalik sandstones are current-bedded which

shows that they have been deposited under varying fluviatile conditions. The Kamlials and the Chinjis contain appreciable amounts of ferruginous matter which should probably have been derived from the Peninsula to the south. The pseudo-conglomerates consist of shale-pebbles whose origin should be attributed to a rather dry terrain and to short transportation. The sediments seem to have been derived both from the north and south, since the soft light-coloured sandstones could have come from the newly risen land in the Himalaya.

Land and fresh water fauna.

The Siwaliks attain a maximum thickness of well over 16,000 feet. They contain, in places, an abundance of a large variety of land mammals, fresh water reptiles and fresh water molluscs. There is therefore little doubt of their having been deposited under fluviatile conditions.

Indobrahm.

Pilgrim and Pascoe consider the Siwaliks to have been laid down by one great river which flowed all the way from the north-east corner of Assam, along the area now marked by these strata up to north-west Punjab and then turned southwards to join the Arabian Sea. No other outlet to sea is supposed to have existed, at least till after the Pliocene. All the rivers of Northern India are supposed to have been its tributaries. The dismemberment of this river is attributed by these authors to local upheaval in the Delhi-Ambala region which separated the Ganges basin from that of the Indus, while the head erosion of some Assam river formed the third basin (of Brahmaputra) which inherited the eastern portion of this river system.

Nature of Siwalik deposition.

The Siwaliks, as already noticed, are over 16,000 feet thick and the outcrops are several miles broad in places. Over the greater part of their length they dip under the Pleistocene and Recent alluvia, so that we do not quite know their extent underneath these later sediments. As Pascoe says, it is difficult to consider the Siwaliks as mere talus-fans, but it appears equally difficult to accept them as the deposits of a single river. They could better be explained as due to deposition in large, extensive, fresh water lakes which were more or less continuous and possibly interconnected by rivers. Into these lakes flowed many streams both from the north and south, with a probable preponderance of material from

the north. The lakes and marshy lands which formed the basins of deposition should have gradually sunk to keep pace with the deposition so as to allow for the accumulation of the large thickness mentioned above. Outlets may have existed for the overflow of the fresh water brought in by the numerous inflowing streams, but this does not imply that there was only a single outlet as postulated by Pascoe.

If a single river was responsible for all the Siwalik formations, it is difficult to conceive of these formations being thick and fairly wide at the very source in north-eastern Assam. Moreover, a river flowing for 3,000 miles needs a gradient which could not have existed in what was apparently a well marked fore-deep. Dr. C. S. Fox (**12**, p. 319) has also called attention to the fact that estuarine conditions existed during the Siwalik times at the place imagined as the source of the Indobrahm:

> "It has been suggested that at the close of the Tertiary era (Siwalik times) a great river having its source in Upper Assam flowed along the base of the Himalaya to the Punjab and so round by the Indus valley to the Arabian Sea of that period. Young rivers cutting back from the Bay of Bengal, presumably the Bhagirathi and the Brahmaputra, have deflected the older Siwalik river or the Indobrahm southwards and produced the modern Ganges and Brahmaputra rivers. However interesting this explanation may be of the birth of the Ganges, its disagreement with many facts can be easily proved, such as the presence of an estuary in Upper Assam close to the supposed source of the Siwalik river."

All geologists who have examined the Tipam sandstones to the south of Sadiya agree that they resemble the Siwaliks closely and are their equivalents. P. Evans (**9**, p. 220) states that the Siwaliks and the Tipams are in all probability continuous with each other underneath the alluvium of the Brahmaputra in the north-east corner of Assam. This would imply that a river in the corner of upper Assam would have just as much chance of flowing towards the Arakan region as towards the Himalayan region.

It is improbable that a river which flowed along what is now the foot of the Himalaya did not seek to find a way out southward through the Rajmahal region. We have endeavoured to show that the Rajmahal gap should have come into existence before the deposition of the Siwaliks and that there is complete absence of a convincing cause of the formation of the gap at a later period. And as the Siwaliks undoubtedly should continue southward underneath the alluvium of Bihar and the United Provinces, there is every reason

to believe in the existence of some connection between the Siwalik basin and the Bay of Bengal.

The Saraswati and the Jumna.

The idea that the Delhi-Ambala ridge has been subjected to an uplift at a very recent date is not convincing. This ridge is a remnant of the ancient Aravalli range and there is no clear evidence of any recent tilt. There is incontrovertible evidence that the Saraswati (Ghaggar, etc.) is a river of historic times, and the drying up of the lower reaches of this river should be attributed merely to the northward march of the Rajputana desert. The great Rajput kingdoms would not have been established in northern Rajputana in an arid region and there is no doubt that even towards the beginning of the Christian Era Rajputana was forested and far from arid. The capture of the upper reaches of the Saraswati by the Jumna does not necessarily imply an uplift; it may merely be due to the head erosion of an upper tributary of the Jumna. Moreover no one has proved that the Jumna is a river of very recent date and that it is due to the Saraswati veering to the south-east from its former south-westerly course.

Siwaliks under Bihar Alluvium.

The absence of visible Siwalik rocks south-eastward towards the Rajmahal gap and the presence of continuous Siwalik deposits westwards along the foot of the Himalaya up to Sind are cited by Pascoe as reasons in support of the Indobrahm. To our mind, these do not preclude the existence of a southward outlet from the fore-deep. In fact, in a recent paper on the Bihar-Nepal earthquake of 1934, Messrs. Wadia and Auden (**38,** pp. 132-137) discuss the evidence and conclude that the Siwaliks extend beneath the gangetic alluvium of Bihar for many miles from their visible outcrops. It is obvious that the continuity of the Siwaliks to the south cannot be apparent when they are covered by younger sediments. Hence our ignorance of the extent of the Siwaliks under the Gangetic alluvium cannot be a point in support of a westward flowing river.

Pilgrim thinks (and with him Pascoe agrees) that the frequent westward pointing V shapes of the Himalayan streams are indicative of their having been tributaries of a westward flowing river. According to Pascoe (**30,** p. 149)—

"The northern limb of each V may be regarded as the remnant of a right bank Indobrahm tributary, which has persisted in its old westerly direction, and has

become more deeply impressed and permanent owing to the upheaval of the Siwalik deposits over which it flows. The southern limb of the V would represent the final position which the capturing stream has taken up."

V-shaped courses of Himalayan rivers.

It is, we think, impossible with our present knowledge to delineate the course of the Himalayan rivers during the Siwalik times. We know, moreover, that tectonic movements of appreciable magnitude have taken place especially in the western part of the Himalayas in post-Siwalik times and these would certainly have produced great changes in the courses of the rivers which existed at the time of the deposition of the Siwaliks. The Siwalik strata themselves have been uplifted perhaps as much as 4,000 feet in post-Siwalik times. The Pir Panjal range also gives evidence of an uplift of the magnitude of some 5,000 or 6,000 feet. These uplifts which were certainly connected with the later phases of the Himalayan upheaval must have had profound influence on the drainage which existed before.

The statement by Pascoe gives the impression that most of the streams have the abovementioned V-shaped course, which generalisation does not appear to be true. The present courses of these rivers may have little in common with previous drainage lines and can therefore not be traced definitely to pre-Siwalik times. In any case the rivers should naturally be expected to cut across the Siwalik strata partly along and partly across the trend of the ranges, *i.e.*, in a general westerly or south-westerly direction in the western Himalayas. The drainage will be dependent upon the structural features of the mountain terrain which it traverses, and on emerging from the Siwaliks will take the direction of the general slope of the plains. Hence, it would appear that the present features cannot be taken as lending support for the argument that these were the tributaries of a westerly flowing Indobrahm.

Evidence of Dolphins.

The similarity between the fauna of the Indus and the Ganges is adduced as further evidence of the existence of the Indobrahm. The main point in this similarity is the presence of closely allied species of dolphins in both the rivers, whereas the dolphins of the Irrawaddy are quite distinct. R. D. Oldham (**26,** p. 443) states in this connection that the closely allied species must have been derived from a common

ancestor of pre-Siwalik age which later adapted themselves to fresh water conditions. He says—

"There is some direct evidence in favour of the more recent origin of the Gangetic outlet in the presence of closely allied species of dolphins in the Ganges and Indus rivers, of a very different generic type from the cetacean inhabiting the Irrawaddi. These two species must be descended from a common ancestor which acquired a fresh water habitat, and the differentiation of the Indus and Gangetic species have arisen from a subsequent separation of the drainage areas. The changes in the course of the drainage over what is now the watershed region, which will be referred to further on, though they opened water communication between the Indus and Ganges rivers, probably did so only in the torrential region, which is not frequented by the dolphins, and the difference existing between the two species indicates more prolonged separation than could have been the case had there been migration from one drainage area to the other, when they were put into communication with each other by the wanderings of the rivers near the present limits of the two drainage areas. We are consequently driven to suppose, either that two closely allied species originated independently of each other, which is extremely improbable to say the least, or that the great bulk of the Himalayan drainage once found its way to the sea by a single delta, instead of two, and this must have been either at the head of the Arabian sea, or of the Bay of Bengal. The indications of the sea having extended up the Indus valley within the recent period and the absence of any similar indications in the delta of the Ganges, make it probable that the former was the original outlet of the drainage and the formation of the gap between the Rajmahals and the Garo hills, and of the Gangetic delta, is geologically of recent date."

Oldham's argument in the above quotation is for supporting a very recent date for the submergence of the portion between the Rajmahal and the Garo hills. The connection between the existence of the dolphins in the two rivers and the age of the submergence of the Rajmahal-Garo ridge seems to be a little far-fetched. It is, of course, to be admitted that the Indo-gangetic dolphins have undergone a fairly long period of evolution to have adapted themselves to a fresh-water habitat. This in our opinion is best explained by the dolphins having evolved from ancestors which existed in the Eocene sea of North-western India. The Eocene sea was shallowed up to some extent, even isolated in patches, during the Himalayan upheaval so that at least a part of the fauna was not free to migrate back to the open ocean. As we have already seen, the continuous series of Siwalik deposits point to the existence of a continuous basin of deposition (*i.e.*, the fore-deep of the Himalaya). During the Siwalik times, therefore, the dolphins had facilities to migrate all along the fore-deep and also to adjust themselves to the gradual incoming of fresh-water conditions. This gives an acceptable explanation of the existence of closely related dolphins in the present

day Indus and Ganges basins. The dolphins of the Irrawaddy, belonging to a region with a different history, should naturally be expected to be different from the Indo-Gangetic ones which evolved over a long period in basins which were cut off from the sea and which grew gradually less saline.

Annandale's view.

Our idea regarding the nature of the area of deposition of the Siwaliks finds support in a paper by the late Dr. N. Annandale (**1**, pp. 144-145) who says that it is not necessary to assume that the Ganges and the Indus were ever connected together as rivers. The Peninsular mass of India was separated from the rest of Asia by a broad strait which was almost marine in nature. By the uplift of the Himalaya this strait gradually became narrow but did not altogether disappear. The streams that drained the southern slopes of the newly formed Himalaya should have brought plenty of detrital material which helped to fill in the depression. Annandale thought that there were large lagoons with interconnecting streams which constantly changed their courses.

Boulder-Conglomerate.

Now let us examine the hypothesis advanced by Dr. Pilgrim in support of the existence of his Siwalik river based on the study of the Boulder Conglomerate zone. At the top of the Siwalik system there is a more or less constant horizon composed of pebbles and boulders in a silty matrix, and of varying composition and thickness. This is the Boulder Conglomerate zone. In certain areas it attains a great thickness as in the region between the Beas and the Chenab forming the ridges bordering on the plains. East of the Beas, it thins down and gradually becomes a series of pebbly sandstones towards Assam. The pebbles and boulders vary in composition in different places. In the Beas-Chenab tract they are composed of white quartzites, dark traps, mumulitic limestones and other Tertiary rocks. Pilgrim has suggested that these Boulder Conglomerates were the result of deposition by a large river which was constantly shifting its course. The materials of these boulder beds, according to him, were brought by tributaries from the Himalayas. The thinness of the boulder beds in Assam is explained as due to this region being near the source of the river and the thickness in the Beas-Chenab region as due to many tributaries.

We have already discussed the improbability of the river having arisen in N. E. Assam and quoted Fox in support of our contention.

In the Beas-Chenab region the thickness of the Boulder Conglomerate is easily explained by the fact that great upheavals were going on in the north-west Himalaya in the Upper Siwalik and post-Siwalik times. At the period we are considering, the Pir Panjal was either not in existence or was only a low ridge which was unable to interfere with the southerly drainage from Kashmir. The quartz boulders and the traps seem to have been derived from the Muth Quartzite and the Panjal traps respectively, while the Tertiaries have also contributed their share of boulders and fine sediments. Again the large width of the formation suggests the improbability of the area of deposition being a flood plain of a single westerly flowing river. The phenomena are better explained on the assumption of its being large lake basins or lagoons which would have permitted the deposition of boulders and finer sediments by glacial rivers flowing down from the hills. For, we know that in the Boulder Conglomerate times the Pleistocene Ice Age had already set in. The absence of such conspicuous Boulder beds in the eastern Himalayas may be due to the uplift of this period not having been important enough to give the necessary rejuvenation and steep gradient to the rivers or the glaciers flowing down from the hills. The Boulder beds therefore do not prove the existence of a large river flowing along the foot of the Himalayas.

X. SUMMARY.

An attempt is made in the preceding pages to show that the hypothesis advocated by Dr. G. E. Pilgrim and Sir E. H. Pascoe of the existence of the Siwalik River (or the Indobrahm) has not enough evidence in support. In reveiwing the evidence, the Tertiary history of the sub-Himalayan zone and the adjacent plains is examined.

In the north-west of India an arm of the Eocene sea extended up Sind, Rajputana and the Punjab to Jammu and thence eastward down to Landsowne and Naini Tal. This sea was apparently connected with the Tethys since the same Eocene fossil assemblage is seen also in the Tethyan or Tibetan zone, eastward up to the meridian of Calcutta. The easternmost exposure in the sub-Himalayan region is near Lansdowne, and it seems to show a shallow-water facies indicating the close proximity of the coast. It is interesting to point out that this limit coincides with the prolongation of one of the eastern ridges

of the Aravallis, which presumably acted as a barrier against the extension of this sea eastward in the sub-Himalayan area.

At this period a ridge also extended from Southern Bihar through Rajmahal hills to the Shillong plateau which separated the Bay of Bengal from the area now occupied by the Ganges-Brahmaputra basin. The Bay of Bengal extended into the southern part of the Shillong plateau since Eocene rocks are seen along its southern border and also some distance further north.

The first upheaval of the Himalaya broke up this Eocene sea in North-West India into isolated basins in which were deposited first the Chharats and later the Murrees, the water gradually losing its saline character, since the Murrees are considered as deposited in brackish water. Probably a 'fore-deep' was formed at this time in the sub-Himalayan region east of the Aravallis also, but there is no evidence to that effect as the younger sediments seem to have completely covered up the older ones.

The next important upheaval in the Middle Miocene times produced a pronounced 'fore-deep' bordering the Himalayas to the south throughout their length. The same upheaval presumably depressed the part of the ridge between the Rajmahal and the Garo hills, for we find that two thrust movements affected the Assam plateau, one from the north and the other from the east. These have produced transverse faults which have sliced the Assam plateau into blocks bounded by north-to-south faults. The Rajmahal gap appears to be a block which has been faulted down as a result of these movements. There is no evidence of such large tectonic movements in this region at a later period which could account for the formation of this gap.

The 'fore-deep' was of the nature of a series of practically continuous lagoons into which flowed numerous transverse streams from the Peninsula and from the newly uplifted Himalayas. The sediments brought by these streams into the 'fore-deep' formed the Siwalik strata, and the great thickness of which (over 16,000 feet) may be attributed to the gradual sinking of the basins of deposition. The large amount of water brought into this 'fore-deep' by the rivers must have found an outlet in the east through the Rajmahal gap into the Bay of Bengal, and other outlet or outlets in the west towards the Arabian Sea.

It is difficult to accept the existence of a Siwalik River or the Indobrahm during this period for the following reasons:—

1. As Dr. C. S. Fox has pointed out, at the place which is supposed to have been the source of this river there are deposits which point to the prevalence of estuarine conditions at this period.
2. It is pointed out that in all probability the Rajmahal gap was formed during the second upheaval of the Himalaya in the Middle Miocene times, *i.e.*, just before the commencement of the Siwalik deposition. When this gap came into being, a westerly flowing river could not have existed in the Siwalik zone of the eastern Himalayan region, for such a river could have found a ready outlet into the Bay of Bengal through this gap. In the north-west Himalaya, the excess waters would have naturally found an exit westward and south-westward, ultimately finding their way into the Arabian Sea.
3. It is unreasonable to expect the vast thickness of the Siwaliks to be deposited in the flood plains of a single river, however large it might have been. The facts are more in keeping with the supposition that the Siwaliks were laid down in a 'fore-deep'.
4. The occurrence of the closely allied species of dolphins in the Ganges and the Indus basins is quite inadequate to support the Indobrahm hypothesis. These dolphins are apparently descended from the marine species which lived in the Eocene sea of North-western India. When the Himalayan movements took place, they became confined to the isolated remnants of the sea but had the opportunity of spreading out into the fore-deep of the Siwalik times and of adapting themselves to fresh-water conditions. It is thus that they are found in the present day Ganges and the Indus.
5. The Boulder-conglomerates should have been deposited by the combined action of several rivers from the north, aided by recent (or partly contemporaneous) uplift and special flood conditions. We have very clear proof that post-Pliocene uplifts took place in the North-western Himalaya where this zone is particularly well developed.

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By
N. K. N. Aiyengar, M.A., *Assistant Geologist,*
AND
M. S. Venkataram, B.A., Offg. *Assistant Geologist,*
Geological Survey of India.

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By N. K. N. AIYENGAR, M.A., *Assistant Geologist*, and M. S. VENKATARAM, B.A., Offg. *Assistant Geologist, Geological Survey of India.*

One of the oft-discussed subjects in Indian geology is the classification of the Gondwana system: whether it should be subdivided into only two, the Lower and the Upper, or into three as, Lower, Middle and Upper. Much has been said in favour of and against either of these classifications based on the available palæontological and stratigraphical information. Though the two-fold division is the oldest, and is supported by the majority of Indian geologists, the upholders of the tripartite division are not negligible. The history of the classification of the Gondwana system has been recently discussed in great detail by Dr. C. S. Fox especially from the floral evidence (**5**, pp. 75-108, 180). It seems worthwhile to review the whole evidence available at present with regard to the age of the various subdivisions of the Gondwana rocks from the point of view of the vertebrate remains and see which of the classifications is nearer the truth.

The early geologists have confined their attention mainly to the floral evidence for the classification of the Gondwanas, but the faunal evidence has not been so far seriously examined. Though the vertebrate fossils discovered in various horizons of the Gondwana rocks have been studied by palæontologists from time to

time and their opinions regarding the age of the fossils recorded in various publications, their views on the age of the rocks in which these fossils occur have not been made use of in the classification of the Gondwana system. Vertebrate fossils found in the Gondwanas, though often fragmentary and confined to a few horizons, are still of much importance as they give us independent evidence with regard to the age of the beds in which they occur; and again in certain cases serve as a check on the floral evidence. But it is unfortunate that most often the fauna and the flora do not occur together.

The vertebrate fossils in the Gondwana rocks are reptiles, labyrinthodonts and fishes. The chief occurrences of these are in the following beds:—

7. Denwa beds on the northern slopes of the Satpura hills of the Central Provinces.
6. Tiki beds of South Rewa in Central India.
5. Maleri beds of Hyderabad (Deccan) State.
4. Panchet beds of Bengal.
3. Mangli beds of Nagpur.
2. Bijori beds south of Pachmari scarp, Central Provinces.
1. *Gangamopteris* beds of Kashmir.

The respective positions of the above beds in the classification of the Gondwana system is given below:—

Umia		Lower Cretaceous	
Jabalpur		Upper	
Kota		Middle	Jurassic
Rajmahal		Lower	
Parsora		Upper	
Maleri, Tiki, Denwa		Upper	
Pachmari		Middle	Triassic
Panchet, Mangli		Lower	
Raniganj, Bijori, Kamthi		Upper	
Barren measures		Middle	
Barakar			Permian
Karharbari (Lr. Barakar)		Lower	
Umaria marine beds			
Rikba stage			
Gangamopteris beds of Kashmir	Talchir	Upper Carboniferous	
Talchir boulder bed			

1. Gangamopteris beds of Kashmir.

Near Khunmu in the Vihi district of Kashmir fish and labyrinthodont remains were discovered associated with plant fossils. These beds are known as the *Gangamopteris* beds of Kashmir and have yielded the following fauna :—

(a) ***Archegosaurus ornatus*** (Amphibia)
(b) ***Actinodon risinensis*** (Amphibia)
(c) ***Amblypterus kashmirensis*** (Pisces)
(d) ***Amblypterus symmetricus*** (Pisces)

Regarding the age of these beds, Dr. Smith Woodward who identified ***Archegosaurus*** and ***Amblypterus*** is of the opinion that the genera are typically lower Permian in age (**21**, p. 10). The plants associated with these have been identified as ***Gangamopteris kashmirensis*** and ***Psygmophyllum*** sp. by Prof. Sir A. C. Seward who considered the flora to be Permo-Carboniferous in age (**21**, p. 8). Later, W. E. Swinton who examined another fossil amphibian collected from the same horizon identified it as ***Actinodon risinensis*** and assigned it to Upper Carboniferous age (**22**, p. 145).

2. Bijori stage.

Many fragments of the fossil remains of a labyrinthodont, ***Gondwanosaurus bijoriensis***, consisting of axial skeleton, mandibles, skull and teeth were discovered in the Bijori beds of the Pachmari scarp, Central Provinces. In discussing the age of this fossil, Lydekker (**13**, p. 12) says that the fossil has affinities to ***Archegosaurus***, but it is more specialised. The specialisation indicates an approach to the higher labyrinthodonts, ***Mastodonsaurus*** and ***Labyrinthdon***. Further he says (*op. cit.*, p. 12).

"Judging from the foregoing, the age of the *Gondwanosaurus* should probably be (homotaxially) permian; and since the balance of evidence is in favour of regarding the Panchet group, which immediately overlies the Bijori group in which *Gondwanosaurus* was found, as of triassic age, the permian age of the Bijori group would accord well with this reference."

In discussing the age of the Bijori fossil Dr. G. de P. Cotter (**4**, p. 29) says that :

"Two amphibians are attributed to the Raniganj Stage of the Damudas, *viz.*, *Gondwanosaurus* and *Brachyops*. The former is allied to *Archaegosaurus* a genus found in the Gangamopteris Beds of Kashmir," (Pal. Ind. New Ser. II, Mem. 2, p. 13) "and occurs at Bijori in the Narbada valley in company with

Sphenophyllum and *Gangamopteris* and other plants which indicate a Raniganj horizon. It is obviously of Permian and not of Triassic affinities."

3. Mangli beds.

A labyrinthodont, *Brachyops laticeps*, was discovered near Mangli about 10 miles north of Warora and 50 miles south of Nagpur. Dr. W. T. Blanford (**1**, p. i) in his note appended to Prof. T. H. Huxley's remarks on the vertebrate fossils from the Panchets, says:

"I have already suggested (Mem. Geol. Surv. Ind., III, p. 134) the probability of the Mangli beds being equivalent in age, or nearly so, to the Panchets of the Raniganj field........"

Regarding the age of this fossil Lydekker (**13**, p. 13) thinks that—

"the labyrinthodont *Brachyops laticeps* from the Kamthi (Mangli) group, which like the Bijori group belongs mainly to the Damuda series, is allied to a European jurassic form (*Rhinosaurus*), while the flora of the Damudas has in many respects a decidedly mesozoic facies. What is already known of the distribution of fossil floras in other parts of the world does not, however, forbid the view that the Damudas as a whole may correspond to the upper palæozoics, with a possibility of their beds being lower triassic."

Thus we find that Lydekker was not in a position to fix the age of the Mangli beds on the faunal evidence available before him, but Blanford considered them to be roughly Panchet in age. According to Dr. G. de P. Cotter, *Brachyops* "is supposed to be closely allied to the genus *Micropholis* which characterises the *Procolophon* zone (Lower Trias) of the Beaufort beds of South Africa. One might therefore doubtfully place the Mangli beds in the Trias." (**4**, p. 29).

4. Panchet beds.

A large number of fossil vertebrates, mostly of labyrinthodonts and reptiles, has been collected from some localities in the Panchet beds just north of Deoli (23° 39′ ; 86° 53′) near Raniganj, Bengal. The early collections were examined by T. H. Huxley (**9**, pp. 1-24) and Lydekker (**11**, pp. 1-36). The fossils are generally fragmentary, consisting of large number of vertebrae, imperfect skulls, ribs, and other parts of the animals. The following genera and species were identified by Lydekker in this collection :—

(*a*) *Dicynodon orientalis* (Reptilia)

(*b*) *Epicampodon* (*Ankistrodon*) *indicus* (Reptilia)

(*c*) *Ptychosiagum* (*Ptychognathus*) *orientale* (Reptilia)

(*d*) *Pachygonia incurvata* (Amphibia)
(*e*) *Gonioglyptus longirostris* (Amphibia)
(*f*) *Gonioglyptus huxleyi* (Amphibia)
(*g*) *Glyptognathus fragilis* (Amphibia)

On the evidence of the labyrinthodont remains of Europe, Huxley says (**9**, p. 24):—

"I do not think it is permissible to affirm that the Labyrinthodonts are either characteristically older Mesozoic or newer Palæozoic—nature seeming to have spread them, with great impartiality, throughout the Triassic, Permian and Carboniferous rocks as far down as the horizon of the English Carboniferous limestone."

Discussing further about the age of the formation in which Labyrinthodonts occur, he says—

"in fact, the Labyrinthodonts, as a group, as effectually bridge over the gap between the Palæozoic and Mesozoic formations, as Teleostian fishes and the Crocodilia bridge over that between the Mesozoic and Cainozoic series: and just as the discovery of skulls of new genera of Percoid fishes, or of Crocodilia, would leave the question of the Mesozoic, or Cainozoic age of the beds in which they occurred, open, so in my judgment, does the occurrence of Labyrinthodont crania in the upper beds of the Raniganj coalfield leave the question of their Mesozoic or Palæozoic age undecided. So far an accumulation of uncertainties may go towards forming a conviction, however, I should incline, in view of the whole vertebrate evidence (to which I confine myself), to the opinion that the Indian fossils are either of Triassic áge, or belong to that fauna which will one day be discovered to fill up the apparent break between the Palæozoic and Mesozoic forms of life."

Lydekker's opinion on the age of the Panchet vertebrates is as follows (**11**, p. 2):—

"Prof. Huxley thought it probable that these rocks might be of triassic age, but considered that the evidence was not sufficient to make this point certain. Prof. Owen (**19**,) correlates the Panchet rocks with the Karoo rocks, Africa, and says that the age of these beds lies between the triassic and the upper carboniferous periods, but inclines to the opinion that they belong to the former, ...while Mr. W. T. Blanford (**2**, p. 82) considers that the Panchet group should *probably* be regarded as of triassic age. It appears to me that, in the absence of a marine molluscan fauna in the Gondwana series (of which Panchet rocks form a group), no exact homotaxis can be made between these rocks and the rocks of Europe, since there is no definite standard of comparison. It is, however, probable that the Panchet group is not very far removed from the triassic."

Thus we find that Lydekker was not even as definite as Huxley in deciding the age of the Panchet fossils.

Dr. Cotter thinks that—

"*Ptychosiagum orientale* is very probably referable to the genus *Lystrosaurus*, a genus which characterises the basal beds of the South African Trias (Lystrosaurus zone)" and adds

"the Panchet Stage has been placed in the Lower Trias and there appears to be good reason for this view." (**4**, p. 28).

Recently some fish remains were obtained from the basal beds of the lower Panchets, south-east of the village called Kukhrakuri (23° 36′ 53″; 86° 58′ 40″) in the Raniganj coalfield by Mr. E. R. Gee (**6**, p. 206). These have been identified by Dr. E. I. White as—

"*Amblypterus*, fishes which lived in the lakes and rivers of the Carboniferous and Permian times."

Further Mr. Gee points out that—

"their occurrence in the basal Panchets (Maitur stage) gives these beds strong Palæozoic aspect and suggests a Permo-Triassic age for the Panchet series."

As a confirmatory evidence it may be pointed out that from the same horizon was obtained fossil flora—near a village known as Alkusa (23° 38′ 45″; 86° 51′ 30″)—which includes distinct *Glossopteris* and *Schizoneura*, characteristic of the Lower Gondwanas.

5. Maleri-Tiki-Denwa.

Reptilian and labyrinthodont fossils have been discovered in three areas: (1) near Tiki (23° 56′: 81° 22′) in South Rewa State, Central India, (2) around Maleri (19° 14′; 79° 38′) in the Hyderabad State and (3) Denwa, on the northern slopes of the Pachmari hills. Tiki and Maleri beds are considered to be of the same age on the evidence of their fossil contents, and the Denwa beds are correlated with the Maleri beds. Lydekker identified (**14**, pp. 1-38) the following fossils collected from the Maleri and Tiki beds.

Reptilia: *Hyperodapedon huxleyi*
Belodon sp.
Parasuchus hislopi
Dinosauria

Amphibia: *Pachygonia incurvata*

Dr. T. Oldham (**17**, pp. 300-307) identified the fossil fishes collected from Maleri as—

Ceratodus virapa

Ceratodus Hunterianus
Ceratodus Hislopianus
Ceratodus Oblongus

Lydekker (**14**, p. 3) in discussing the age of the Maleri-Tiki-Denwa beds expressed his doubt as regards the desirability of comparing the Gondwana fauna with distant faunas of Europe. However, he placed the Tiki-Maleri-Denwa fossils in the upper Trias (Rhætic and Keuper). Blanford in dealing with the age of the reptilian remains (**3**, p. 19) of Tiki and Maleri, stated that the genera *Hyperodapedon* and *Parasuchus* are Triassic as both genera occur in European Trias.

Further collections were recently made from the Maleri and Tiki beds and the following fossils have been identified by Prof. F. von Huene (**7**, p. 39) as follows :—

Labyrinthodont :	*Metoposaur*
Reptilia :	*Paradapedon huxleyi*
	Paradapedon (?) *indicus*
Phytosauria :	*Brachysuchus* (?) *maleriensis*
Saurisuchia :	Vertebrae

The entire fossil collection as usual, is fragmentary. Prof. von Huene says that:

"The Labyrinthodonts all belong to the Family Metaposauridae, which is characteristic of the lower part of the Upper Trias. Apparently the Indian forms are particularly related to the North American genera *Anaschisma* and *Buetteneria*......

The nearest recognisable relations to the Indian Phytosaurs are found in the lower level of the North American Upper Trias (Dockum beds of Texas and Chinle beds of Arizona and New Mexico) (31)................

In considering the described fauna as a whole, it is seen that Rhynchosaurids, Phytosaurs, and Metaposaurids are predominant and are groups which evidently are typical (32) of the lower part of the Upper Trias, that is to say the Lower Keuper of the northern hemisphere. In the Trias Saurischians are confined to the Upper Trias. The occurrence of the Phytosaurs and Rhynchosaurids is against assigning the beds to the upper part of the Upper Trias (Upper Keuper)". (**7**, pp. 39-40).

As regards *Ceratodus*, according to Miall (**15**, p. 16) and Blanford (**3**, p. 19) it is chiefly characteristic of Triassic and Rhætic beds of Europe.

A fossil amphibian collected from the Denwa beds has been identified as *Mastodonsaurus indicus* by Lydekker (**14**, p. 3) and his opinion regarding the age of these beds has already been mentioned. Dr. Cotter is also of the opinion that *Mastodonsaurus*

indicus in the Denwa beds indicates a Rhætic—Keuper age to these beds (**4,** p. 26).

6. Kota beds.

These beds which are younger than Tiki-Maleri-Denwa beds are well developed around Kota near Sironcha in Central Provinces. The following fossils have been identified from these beds (**10,** p. 125) :—

Pisces : *Lepidotus deccanensis*
L. longiceps
L. breviceps
L. pachylepis
L. calcaratus
Tetragonolepis oldhami
T. analis
T. rugosus
Dapedeus egertoni

As all these genera are found in the Liassic of Europe, the Kota beds can be assigned to Lias.

The Umia (marine) beds have yielded *Plesiosaurus* remains, *i.e.*, *Plesiosaurus indicus*, which is said to range in time in Europe from "Lias to Chalk inclusive" (**11,** p. 28) but this genus is not of any help in deciding the age of the Umia beds as their age can be more accurately determined by their marine fossil contents.

Conclusion.

We have so far studied the views of various palæontologists on the age of the fossils examined by them. Now we may summarise these facts in relation to the classification of the Gondwana system.

Gangamopteris beds of Kashmir.—*Amblypterus* and *Archegosaurus* from these beds are considered by Woodward to be of lower Permian age while *Actinodon* from the same horizon is assigned to upper Carboniferous by Swinton. In Europe we find that these three fossils are confined to lower Permian (*see* chart on p. 11). Hence it seems reasonable to fix the age of the *Gangamopteris* beds of Kashmir on the faunal evidence to range from Upper Carboniferous to Lower Permian. Prof. Seward's opinion based on floral evidence confirms this view.

Bijori beds.—*Gondwanosaurus* is considered to be closely allied to *Archegosaurus* which is found in the *Gangamopteris* beds of Kashmir; but it is more specialised. Though it is generally unsafe to fix the age of any bed on the strength of a single new genus, here it seems reasonable to assign the Bijori fossil to Lower to Middle Permian on the above evidence. Lydekker and Cotter are also of the opinion that the Bijori fossil indicates a Permian

The Mangli fossil *Brachyops laticeps*, according to Lydekker, points relationship to a Jurassic form *Rhinosaurus*, while according to Dr. Cotter this animal has great affinity to *Micropholis* which is characteristic of the Lower Trias of South Africa. Dr. Cotter's view seems to be nearer the truth.

Panchet beds.—Huxley points out (9, p. 24) that at first sight it is difficult to assign the labyrinthodonts of the Panchets either to the Palæozoic or Mesozoic as they range from Carboniferous to Permian with Triassic affinity. Prof. Owen correlates the Panchets with the Karoo beds of Africa and considers these beds to range from Upper Carboniferous to Trias, whereas Lydekker feels that it is unsafe to correlate beds of distant places on their fossil evidence but still thinks that the Panchets are not far from Triassic in age. Dr. E. I. White thinks that the *Amblypterus* in the Panchets is Carboniferous—Permian.

We have seen that all the earlier palæontologists have indicated a more or less Triassic age for the Panchet fossils but when the collection is compared with similar fauna in other parts of the world, we find conflicting evidence. For instance, *Dicynodon* of the Panchet age is confined to the Permian of Europe whereas it is found in the Beaufort beds (Lower Triassic) of South Africa and also in the Trias of North America. *Amblypterus*, which occurs in the Maitur stage of the Panchets and also in the *Gangamopteris* beds (Permo-Carboniferous) of Kashmir, is confined to the Lower Permian of Europe. *Epicampodon*, a doubtful dinosaur has also Triassic affinity. When we consider the actual position of the Panchet Reptilian Bone bed we notice that it occupies a middle horizon. It is above the Maitur stage where *Amblypterus* and *Glossopteris* flora were discovered. If the Maitur beds represent about Upper Permian, the Bone bed and the unfossiliferous beds above may represent the Lower Trias. Hence the Panchets can be said to range from Upper Permian to Lower Trias. This

explanation agrees with the views expressed by many palæontologists that the Panchet fossils have Triassic affinities, especially with those of South Africa and it is reasonable because evolution of life cannot be sudden, but is a gradual process. Generally fossils in the lower beds either persist into the higher beds or the fauna or flora of the younger beds show some affinity at least to those of the lower when there is continuity of life.

Considering the fossils found in the next younger beds, Maleri-Tiki-Denwa, we find that with the exception of *Pachygonia incurvata* no other Panchet fossil persists into these beds. They are distinctly of Upper Triassic age and many of the genera are found in the Triassic beds of other parts of the world. The appearance of *Massospondylus*, a definite dinosaur in the Tiki beds is the precursor of the Cretaceous dinosaurs of the Lametas.

In Peninsular India the geological conditions were not the same as in Europe at least in the Gondwana period. There may be strong reasons to divide the geological time in Europe into Palæozoic, Mesozoic and Cainozoic, but even this major division is not easily discernible in the Indian Peninsula. There appears to have been continuity of life and deposition in India from the Palæozoic to the Mesozoic in the Gondwana period. The climatic condition of the Gondwana period seems to have been fairly uniform, but with a definite tendency to progressive desiccation after the glaciation up to the disappearance of the *Glossopteris* flora, when luxuriant vegetation flourished due to moist and warm conditions, *i.e.*, from the Talchirs (Carboniferous) to Lower Panchets (Upper Permian). Then began drier conditions when the *Glossopteris* flora died out; but the next wet conditions (of lesser degree) did not commence until the Rajmahal times. This interval is the period from Lower to Upper Trias. Some geologists are of the opinion that there might have been a break in the deposition about the Middle Trias when land conditions were maximum with least deposition.

Taking all facts into consideration, it seems most reasonable to include all the strata containing fauna and flora with distinct Palæozoic characters, although including some with Mesozoic affinities, into a lower subdivision, and the others containing fossils with distinct Mesozoic characters into an upper subdivision. Such a subdivision can be easily made by including all the beds containing the *Glossopteris* flora and the Panchets with strong Palæozoic characters in Lower Gondwana while the Maleri to Umia, beds with un-

mistakable Mesozoic fauna and flora can be grouped as Upper Gondwana.

Comparative list of fossils based partly on Lydekker's table.

(*Pal. Ind.*, Ser. IV, Vol. I, Pt. 5, p. 2, 1885.)

	EUROPE		INDIA	
UPPER GONDWANA	Jurassic: Lias	*Lepidotus* *Tetragonolepis* *Dapedeus*	Kota	*Lepidotus pachylepis* *Lepidotus deccanensis* *Lepidotus longiceps* *Lepidotus breviceps* *Lepidotus calcaratus* *Tetragonolepis oldhami* *Tetragonolepis analis* *Tetragonolepis rugosus* *Dapedeus egertoni*
	Upper Trias	*Belodon* *Hyperodapedon* *Rhynchocephalus* *Mastodonsaurus* *Metoposaur* (*Metopias*)	Maleri-Tiki	*Paradapedon* (*Hyperodapedon*) *huxleyi* *Paradapedon* ? *indicus* *Brachysuchus* ? *maleriensis* *Belodon* sp. *Parasuchus hislopi* *Metoposaur* (*Metopias*) *Massospondylus* *Pachygonia incurvata*
			Denwa	*Mastodonsaurus indicus*
LOWER GONDWANA	Lower Trias	*Dicynodon* *Trematosaurus*	Panchets	*Dicynodon orientalis* *Epicampodon* (*Ankistrodon*) *indicus* *Ptychosiagum* (*Ptychognathus*) *orientale* *Pachygonia incurvata* *Gonioglyptus longirostris* *Gonioglyptus huxleyi* *Glyptognathus fragilis* *Amblypterus*
	Permian	*Amblypterus* *Actinodon* *Archegosaurus*	Bijori	*Gondwanosaurus bijoriensis* *Brachyops laticeps*
	Permo-Carboniferous		*Gangamopteris* beds of Kashmir.	*Amblypterus kashmirensis* *Amblypterus symmetricus* *Actinodon risinensis* *Archegosaurus ornatus*

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MANGANESE-ORE IN BAMRA STATE. BY M. S. KRISHNAN, M.A., PH.D., A.R.C.S., and P. K. GHOSH, M.Sc., D.I.C., D.Sc., *Geologists, Geological Survey of India.* (With Plates I to III.)

CONTENTS.

I. INTRODUCTION.

The occurrence of manganese-ore in Bamra, one of the States under the Political Agency of the Orissa Feudatory States, was brought to light by Mr. Girija Shankar Deb, formerly Forest Officer of Bamra, who evinced considerable interest in minerals. Mr. Deb came across some lumps of manganese-ore in the hill near Pukhura (21° 35′ 30″ : 84° 17′) in the south-west corner of Bamra. A specimen which was analysed by the Government Test House* at

Calcutta showed about 54 per cent. manganese. In the field-season 1937-38, this was brought to the notice of Dr. M. S. Krishnan, who was able to map the area containing the manganese-ores and conduct a preliminary examination of them in the same season. The microscopical investigation of the ores was carried out by Dr. P. K. Ghosh, and the sections VII and VIII-A, embodying the results of the examination, have been contributed by him.

The first author wishes to express his thanks to the State authorities of Bamra for the excellent facilities given him during the course of the field-work in their jurisdiction.

Acknowledgment.

At his suggestion they also put down pits in different parts of the manganese-ore deposits and had three samples of the ore analysed (by the Government Test House, Calcutta) which are used here with their kind permission.

Our thanks are also due to our colleague, Dr. J. A. Dunn for much help received during the examination of the ore-minerals under the reflecting microscope.

II. PREVIOUS WORK IN BAMRA.

No geological work has been done in Bamra prior to 1925. In that year Mr. H. C. Jones, assisted by Dr. M. S. Krishnan, conducted a rapid reconnaissance of the whole State (area roughly 2,000 square miles) during the course of about three months, and gained a general idea of the geology, which is summarised in the General Report of the Geological Survey of India for that year (*Records Geol. Surv. Ind.*, LIX, p. 64, 1926). Though Mr. Jones had noted the occurrence of much limonite and lateritised rock in the neighbourhood of Jamunkira (21° 32′ 30″ : 84° 24′), the presence of manganiferous ores in them was not recorded.

III. GENERAL GEOLOGY.

Country Rocks.

Granitic gneiss.

During the course of mapping on standard sheet 73 C/6 (scale 1″=1 mile), in which the occurrence of manganese-ore was reported by Mr. Deb, Dr. Krishnan found certain lateritised zones in which the ore invariably occurred. The country rock in the south-western part of the sheet is a gneissic granite which extends northwards as far as Kuchinda (21° 45′ : 84° 21′), westwards into Sambalpur, and eastwards into Bonai

State. This granitic rock is very probably part of the same batholithic mass which occurs in Bonai.[1] It is generally distinctly banded and gneissic in the area surveyed, the banding being due to its composite nature. It includes streaks and lenses, often partly assimilated, of mica-schists. The included lenses of schists have often developed garnet, and in rare cases sillimanite, as a result of metamorphism. In some places, *e.g.*, near Nagarabahal (21° 42′ : 84° 19′) the rock is massive and granitoid but is never entirely free from a slight streakiness.

Microscopic characters.

The rock generally consists of quartz, orthoclase, microcline and acid plagioclase, the last being rather subordinate. The felspars often show micro-perthitic structures, while myrmekitic patches are also occasionally seen. Biotite and some hornblende are common, and these are fairly abundant in the markedly gneissic varieties. The accessory minerals are iron-ore, sphene and apatite. Muscovite is distinctly subordinate to biotite and hornblende. Tourmaline is rare and generally absent, thus contrasting strongly with the granite of southern Ranchi and Gangpur[2] in which this mineral is abundant. Pegmatitic modifications are seen though not abundant and this may indicate that erosion of the upper part of the mass has proceeded to a greater depth here than in the granite of Southern Ranchi.

Strike of foliation.

The general direction of the foliation of the schists as also of the banding of the granite is approximately W. 30° N.—E. 30° S., subject to slight variations. This direction of the fold-axis (which varies to N.W.-S.E.) prevails in southern Bonai, Pal Lahara and the Mahanadi valley. The dip of foliation is high either to the north-east or to the south-west and may frequently be vertical.

Basic rocks.

In the area with which this paper is concerned (sheet 73 C/6) the north-eastern portion shows ridges of quartzite and quartz-schist which, together with the mica schists (now occurring as lenses in the granitic gneiss), are pre-granite in age. There are also several, more or less parallel, 'sills' of basic igneous rock, particularly in the south-western portion. These sills run mainly parallel to the direction of regional foliation, though occasionally they are transgressive and become

[1] H. C. Jones: The Iron ores of Bihar and Orissa. *Mem. Geol. Surv. Ind.*, LXIII, Pt. 2, p. 215, (1934).
[2] M. S. Krishnan: The Geology of Gangpur State. *Mem. Geol. Surv. Ind.*, 71, pp. 110-117, (1937).

dykes. They are mainly doleritic in nature and consist of plagioclase (andesine to labradorite) and ophitic augite which usually shows some uralitisation and saussuritisation. Ilmenite and sphene are the common accessories. When coarse, they may be called diorite-gabbro or gabbro. A few of the sills are of the nature of pyroxene-granulite, consisting of pyroxene, plagioclase, some quartz and occasionally garnet. In one occurrence the pyroxene was found to be hypersthenic. Hornblende-pyroxenite or hornblende-biotite-gabbro have also been met with.

The basic sills in the south-western part of sheet 73 C/6 all seem to be later than the granite and may possibly be of the same age as the Newer Dolerite of Keonjhar and South Singhbhum. It may however be noted that they are different in composition, since quartz dolerites with granophyric structures are uncommon among those examined in Bamra.

IV. LATERITISED ZONES.

A few intensely lateritised zones are seen amidst the country described above. They are disposed parallel to the schistosity of the country rock and form long hillocks with rounded outline which can often be clearly distinguished from a distance. There is a tendency for portions of the zones to run *en echelon*, keeping to the general trend. They are enumerated below:—

1. From Nakatipali (21° 37′ : 84° 15′) to Tikiba (21° 33′ 30″ : 84° 20′) with a slight break at Phasimal (21° 36′ : 84° 17′). This zone is continued in the hill three-quarters of a mile south of Kuagola (21° 33′ : 84° 22′).

2. A small ridge through Badibahal (21° 33′ 30″ : 84° 19′).

3. Hillock at Kuagola and the long hillock half a mile south-west of Jamunkira (21° 32′ 30″ : 84° 24′); slightly out of alignment with this is a thin zone at Darhia (21° 32′ : 84° 25′).

4. From Mukteshwar (21° 33′ 30″ : 84° 22′) to mile 22 on the Deogarh-Jamunkira road.

5. A low ridge half a mile east of Tiklipara (21° 31′ 30″ : 84° 27′); this however runs in a N.N.W.-S.S.E. direction askew to the general direction of foliation.

6. From Kumbhiachuan (21° 36′ : 84° 20′) to north of Sarai (21° 35′ : 84° 22′).

In addition to these, there are a few smaller patches of the same nature located at:—three-quarters of a mile south-west of Guljipali

(21° 36′ 30″ : 84° 18′ 30″); Jamumal (21° 37′ : 84° 21′ 30″); one mile north-west of Jamumal; a quarter of a mile east of Nuadihi (21° 38′ : 84° 24′); and one mile W.N.W. of Nuadihi.

Distribution of ore.

The soil of these zones is dark brown to reddish brown and contains interspersed lumps of limonite and manganese-ore. Large boulders, some apparently *in situ*, are also exposed in these zones. Some of the boulders are of silicified breccia, while others are of angular fragments of ferruginous quartzite or siliceous limonite cemented by abundant anastomosing veins of chalcedonic or opaline silica. Others consist mainly of limonite traversed by veins of manganese-ore (psilomelane). Occasionally also we find a schistose lateritised rock in which grains of quartz are found cemented by limonitic material. Though the original minerals of such rocks have been completely altered and replaced, their scaly structure suggests biotite or chlorite. These lateritised boulders are found particularly along the top of the ridges. Their surface is often found ribbed with veins standing out prominently which, on closer examination, prove to be manganese-ore. When broken, the veins show a banded structure. The boulders may also contain cavities lined with psilomelane, botryoidal limonite and soft pyrolusite.

Boulders.

The lumps interspersed in the soil are of sporadic distribution. Surface observations and data from a few pits point to the conclusion that they are more abundant at the ends, on the flanks, and near the foot of the hillocks than on the top. The ends on the hillocks are perhaps richer in them than other places.

Lumps of ore.

When coming across these lumps lying on the surface, it is not at first easy to say whether they are of limonite or of manganese-ore, unless they are broken by a hammer. After some experience, however, a distinction can be made in most cases without difficulty, since the manganese-ore lumps are more rounded and tend to show rounded botryoidal prominences. Moreover the highly manganiferous nodules are black while the limonitic ones are distinctly brown. Nevertheless there are gradations between the two, many of the lumps being manganiferous limonite.

Botryoidal lumps.

On breaking the manganese-ore nodules we see that they are composed mainly of rather soft pyrolusite, sometimes with thin veins of bright psilomelane. Botryoidal nodules are found especially in the Mukteshwar-Jamunkira band and in the road section east of Tiklipara. When broken open, they show concentric structures and are composed of limonite, pyrolusite and occasionally grains of quartz in the centre.

V. DESCRIPTION OF THE OCCURRENCES.

Naktipali-Phasimal.—In the Naktipali-Phasimal band, only lumps of limonite are seen near the former village. Where this goes through the northern border of the Binjipali Reserved Forest, there is equally no enrichment in manganese. Further east, about one mile due west of Phasimal, the zone is heavily limonitised, and a few lumps of manganese-ore were found, especially on the southern flank. Near the Baunsen *nala* also manganese-ore is present, but sparsely distributed.

Pukhura.—At the western end of the Pukhura village several pieces of manganese-ore were picked up. Two pits were put down here close to the *dera-ghar* (rest house) at a distance of 150 ft. from each other (pits Nos. 7 and 8). Each of these was taken down to a depth of 10 ft. Pit 7 gave only a few lumps which showed nests of pyrolusite in a highly lateritised material. Pit 8 gave somewhat better results but even when the material was broken and sorted, the manganese-ore was visibly of low grade and amounted on the whole to only about 2 maunds[1] (160 lbs.).

Pits Nos. 5 and 6 were located south-east of Pukhura, No. 6 being at the foot of the hill and No. 5 a little up the low flank, just inside the forest. Both these gave much limonitic material together with some manganiferous limonite.

Pukhura-Khairdihi-Krimaloi.—The hill between Pukhura and Krimaloi (21° 35′ : 84° 18′ 30″) shows large masses and boulders of limonite along the top, much of it having the appearance of being *in situ*. Crusts and veinlets of psilomelane are found on these masses. The flanks and the ends of the hill show fragments of highly lateritised schistose rock and lumps of limonite and manganese-ore.

The lumps, when broken, show a rather porous or cellular mass consisting of dark brown patches of limonite and black patches of

[1] One maund=82$\frac{2}{7}$ lbs. avoir.

manganese-ore. Nests of dusty pyrolusite, grains of quartz and occasionally even tiny patches of kaolin are found in the lumps. The more manganiferous lumps are made up mainly of pyrolusite, but part may be psilomelane, especially in the form of veins traversing the pyrolusite and manganiferous limonite. Sometimes concentric and mammillary layers of psilomelane are found superposed on one another, the surface of the layers and any cavities among them being coated with soft pyrolusite. A few lumps were also found which consisted of radiating fibrous limonite, the fibres being perpendicular to the curvature of the concentric layers.

Pit No. 4 at the eastern brow of the hill just south of Khairdihi (3 furlongs north-west of Krimaloi) yielded only a few large lumps of limonite with thin veins of manganese-ore. It is apparently too close to the massive boulders of the top of the hill.

Pits 1, 2 and 3 on the eastern flank (or end) of the hill, a little to the S.S.W. of Krimaloi gave the most promising results of all the bands in the area mapped. Of these, pit No. 1 was only a few feet above the level of the pass connecting Krimaloi with Bandhbhag village which lies to its south. Pits Nos. 2 and 3 were located up the same flank at distances of 100 ft. from each other. Of these, No. 3 was entirely soil to a depth of 7 feet with only a few lumps appearing in the lower portion. Pit No. 2 was entirely in soil for the top 4 feet, lumps of ore appearing below this depth. The lower portion, of mixed soil and lumps, gave about 2 *maunds* of lumps per cubic yard of material excavated. About a half to one-third of the lumps was manganese-ore of fair quality. Pit No. 1 was deepened to 17 feet, the whole of which, except one foot of the top, gave lumps of ore. The material near the bottom was quite damp and the lumps comparatively soft. The total amount of lumps of limonite and manganese-ore recovered from this pit was about 40 *maunds*, which was broken up and hand-picked, eliminating limonite and very low grade ore. The amount thus concentrated was about 26 to 27 *maunds* (say about 1 ton) of fair quality. This 'concentrate' represented about 1 to 1½ per cent. by volume of the material excavated and a little over 1 *maund* (about 90 lbs.) of ore per cubic yard of earth.

Krimaloi-Tikiba-Jamunkira.—Between Tikiba and Krimaloi lumps of ore were seen on the southern flank of the hill north and north-west of Rankibahal (21° 34′ : 84° 19′) and north and north-east of Badibahal (21° 33′ 30″ : 84° 19′ 30″). The band passing

through Badibahal seems to be very poor since only a few pieces from here showed any ore The occurrences around Kuagola (21° 32′ 30″ : 84° 22′) are not at all promising. The thin zone south of Jamunkira yielded a few lumps of manganese-ore, about 5 feet below the surface. A shallow section of this was visible as excavations had been made at its eastern end for the purposes of obtaining 'moorum' for road-making. The top 1 to 5 feet is red soil in which occur very highly altered and lateritised gneissic rock especially in the centre of the knoll. The ore lumps were found in the excavation on the southern flank. The distribution of manganese-ore in this locality as well as in the patch near Darhia is far too sparse to be of any economic importance.

Mukteshwar-Jamunkira.—In this zone, which extends from Mukteshwar to mile 22 on the Deogarh-Jamunkira road, lumps of manganese-ore are found in several places, except near the western end. Large blocks of limonite with encrustations and veins of manganese-ore are found alongside the Jamunkira-Bhojpur road and also further east. The lumps are particularly abundant in the hillock just north of Jamunkira and also on the southern flank and eastern end of the hill further east (*i.e.*, hill marked 1225).

Tiklipara.—At 20 miles 4½ furlongs on the Deogarh-Jamunkira road, a low ridge crosses the road in a N.N.W.-S.S.E. direction. In this cutting (southern side of the road) a large number of lumps of botryoidal manganese-ore were collected. This ridge continues S.S.E.-wards for over two miles and shows lumps of ore in several places.

Four pits were put down along the eastern flank of this zone each to a depth of 8 feet every 50 yards from the road cutting southwards. The first pit (50 yards south of the road-cutting) yielded less than half a *maund* of lumps per cubic yard. Pits 2 and 4 yielded little or no good manganese-ore. Pit 3 gave the best yield of the four, amounting roughly to ¾ *maund* of lumps per cubic yard of material excavated.

Sarai and Nuadihi.—Manganese-ore was found only at two localities amongst the other occurrences mentioned. These are the pass between Sarai and Kiajharan, and the hillock just north-east of Nuadihi. In the other bands there is either no segregation of manganese-ore or it is so poor in quality that further attention is not worth while.

VI. COMPOSITION OF THE ORE.

A few specimens were selected, from amongst the large number collected in the field, for analysis in the laboratory of the Geological Survey of India. The ore recovered from the following pits—Khairdihi 1 and 2, and Tiklipara 3—was broken and hand picked to improve the grade, as mentioned already, and a sample was taken from each and sent by the State for analysis by the Government Test House at Alipore, Calcutta. The analyses are shown in the following table:—

TABLE 1. *Analyses of Manganese-ores from Bamra.*

	1	2	3	4	5	6	7	8	9	10	11
MnO . .	48·25	41·53	37·76	35·00	31·61	32·93	22·02	16·77	38·00*	32·40*	17·80*
Fe_2O_3 .	28·74	33·47	38·59	48·31	19·29	38·59	60·01	63·00	21·00	36·00	40·92
SiO_2 .	0·72	2·42	3·70	1·64	11·26	3·21	3·58	5·51	11·70	0·80	11·56
TiO_2 . .	..	..	..	..	..	..	..	..	1·03	0·50	0·45
Al_2O_3 .	..	..	..	..	..	..	..	..	10·37	6·10	5·83
CaO . .	..	..	..	..	..	..	..	..	0·50	0·60	0·60
MgO .	..	..	..	..	..		..	..	0·42	0·54	0·42
BaO . .	4·38	2·60	0·68	0·87	6·61	1·38	0·30	0·83	2·56†	2·06†	1·92†
S . .	0·15	0·08	0·24	0·18	0·05	0·05	0·04	0·21	..	..	..
P_2O_5 . .	0·62	0·05	0·24	0·27	0·13	trace	0·29	0·03	0·20	0·27	0·40
H_2O- .	..	..	..	..	..	..		..	1·03	0·98	1·08
H_2O+ .	..	..	..	..	..	..	..	..	11·32	10·12	9·67
Fe . .	22·34	26·02	30·00	33·66	15·00	30·00	47·37	48·97	16·89	27·98	38·80
Mn . .	37·36	32·16	29·24	27·11	26·80	25·50	17·05	12·99	28·02	23·34	12·82
Total Fe + Mn .	59·70	58·18	59·24	60·77	41·80	55·50	64·42	61·96	44·91	51·32	51·62

* Reported as Mn_3O_4; † Reported as $BaSO_4$.

Specimens (analysed by R. B. Ghose, Geological Survey Laboratory).

1. Hill E. of Jamunkira (sp. No. 81. H.).
2. Khairdihi near pit 3 (149).
3. Khairdihi pit 1.
4. Jambakulia (near Saral) (156).
5. Tiklipara road cutting (89).
6. Between Tikiba and Badibahal (121).
7. Khairdihi pit 2.
8. Rankibahal (113).

Pit samples (analysed by the Government Test House).

9. Tiklipara pit 3.
10. Khairdihi pit 1.
11. Khairdihi pit 2.

As is usual with lateritic ores, the analyses given above show a great variation in the abundnace of manganese and iron oxides as well as other constituents. The manganese content ranges between 13 and 37 per cent., and the iron content between 15 and 49 per cent. The P_2O_5 ranges from 0·03 to 0·62 per cent., the average value for the 11 analyses being 0·23 per cent. Only partial analyses were done in the Geological Survey laboratory so that all the usual constituents are not shown, but a general idea of the content of Al_2O_3, CaO, MgO and water can be gained from the last three analyses in Table 1.

For purposes of comparison we append below some analyses taken from Sir Lewis L. Fermor's memoir on the "Manganese-ore Deposits of India", (*Mem. Geol. Surv. Ind.*, Vol. XXXVII, pp. 389 and 510-513, 1909). These are mainly of ores of similar lateritic origin from various parts of India.

TABLE 2.—*Analyses of ferruginous manganese-ores (mainly lateritic) from various parts of India.*

District		Manganese	Iron	Silica	Phosphorus
Singhbhum	Range	4·23 –20·66	25·60–41·30	14·70–18·10	0·35–1·18
	Mean	11·84	34·93	16·46	0·74
Belgaum	Range	8·34 –60·85	0·1–51·88	0·65–2·7	0·01–0·12
	Mean	44·77	10 33	1·40	0·035
Dharwar (Sangli)	Range	19·45 –38·48	13·3–25·3	7·0—31·0	..
	Mean	31·62	16·8	19·1	..
Jubbulpore	Range	6·20 –25·6	19·17—47·10	4·40—23·40	0·02—0·85
	Mean	20·26	28·78	12·99	0·25
Ganjam		23·44	19·70	10·25	0·71
Sandur	Range	39·17—54·30	5·38—19·40	0·43—1·00	0·02—0·03
	Mean	47·75	11·45	0·61	0·030
Vizagapatam	Range	32·21—40·05	4·80—15·70	1·10—10·30	0·13—0·48
	Mean	42·96	11·22	4·29	0·27
Shimoga	Range	34·51—55·94	4·01—17·25	0·22—5·75	0·01—0·14
	Mean	37	15	4	0·035
Goa (Kulan)		38·30	20·58	2·24	0·139
,, (Funuswadi)		21·32	39·53	2·70	0·167
,, (Servona)		38·37	20·70	2·16	0·195

Minor Constituents ; Baryta.

An interesting feature of the analyses in Table 1 is the BaO content shown. One specimen, a botryoidal lump from the road-cutting near Tiklipara shows as much as 6·61 per cent., and another from the hill east of Jamunkira shows 4·38 per cent. of this constitutent. In the Government Test House analyses this constituent has been calculated into barium sulphate and reported as such. Fermor mentions (*Mem. Geol. Surv. Ind.*, XXXVII, p. 522) that BaO was found in most of the 78 analyses carried out by J. and H. S. Pattinson, on Indian ores from various localities.

The largest amounts were found in pyrolusite-psilomelane and hollandite ores : - 13·76 per cent. in psilomelane with pyrolusite from Bisrámpur, 15·08 per cent. in psilomelane from Tekrasai, both these localities being in Singhbhum ; 17·59 per cent. in a specimen of hollandite from Kajlidongri. The average for the 78 analyses was 1·88 per cent. while that for 22 analyses of ores from the Vizagapatam district was 2·03 per cent. the range being from 0·03 to 9·53 per cent. It is presumed that the baryta is present in the ores as barium-manganate (Ba_2 Mn O_5) or some similar compound. This constituent seems to be particularly abundant in pyrolusite, polianite, psilomelane and hollandite, though most manganese-ores contain a small quantity.

Zinc oxide.

CaO and MgO are present in appreciable quantities as shown in analyses 9 to 11. The zinc-manganese mineral chalcophanite has been identified under the reflecting microscope in some of the ores from Bamra (*see* p. 16). The presence of zinc has also been confirmed by means of micro-chemical tests on the ore. Though no attempt has been made to determine ZnO quantitatively in the specimens analysed, manganese-ores are known to contain this in measurable quantities, for Fermor has recorded (*loc. cit.*, p. 527) that 15 out of 25 ores analysed showed this constituent, the maximum being 0·55 per cent. and the average being 0·102 per cent.

VII. MICROSCOPIC EXAMINATION.

A microscopic examination of the ores in thin as well as in polished sections reveals the presence of several minerals, some of which undoubtedly represent the original constituents of the country-rock, while the remainder are of secondary origin.

The following minerals have been detected : (1) Quartz, (2) Chalcedony, (3) Biotite, (4) Tourmaline, (5) Magnetite, (6) Hæmatite,

(7) Limonite, pseudomorphous after hæmatite, (8) Limonite, amorphous, (9) Gœthite, (10) Polianite, (11) Pyrolusite, (12) Psilomelane, (13) Psilomelane component No. 3, (14) Chalcophanite.

Primary (rock forming) minerals.

Quartz in its textural relationship to the manganese minerals is best seen in thin section. It is often shattered and shows undulatory extinction. Later manganiferous solutions permeate and to a considerable extent replace quartz along cracks (*vide* Pl. 1, fig. 1, thin section, No. 26,638).

Chalcedony, introduced mainly during the lateritisation of the country-rock, has replaced quartz, partly or completely. It shows a colloform structure and is associated in parallel bands with gœthite, sometimes alternating with it. It is perceived even in hand specimens and is characterised by a reddish brown colour due to the presence of gœthite.

There is also some evidence of the existence of pre-lateritic chalcedony. Like quartz, this shows signs of replacement by manganiferous solutions. Patches of chalcedony (pre-manganese chalcedony) occur in varying sizes and show varying degrees of corrosion by manganese minerals. Quartz and chalcedony are by far the most prevalent of the original minerals of the country-rock.

Biotite.—Only a single flake of corroded and partly bleached biotite has so far been met with in thin sections of the ores. There are, in addition, some wisps of limonite or gœthite associated with interfoliar chalcedony, which together simulate biotite crystal outlines; it is possible they represent the biotite of the original country-rock. Compared with quartz, these doubtful biotite pseudomorphs are insignificant in amount.

Tourmaline.—A few grains of a greenish yellow, idiomorphic but shattered tourmaline, veined by manganese-ore, are noticed. Unlike quartz, these do not show any sign of corrosion. The origin of the mineral is probably connected with granitic intrusion into the mother-rock.

Primary ore minerals.

The ore minerals which have been detected in polished sections are the following:—

Magnetite is observed under the microscope as isotropic grains of a grey colour with a slightly reddish tinge; sometimes a bluish tinge, indicative of a higher state of oxidation of the mineral is also

observed. Magnetite is invariably accompanied by hæmatite which is generally found along the octahedral cleavage planes (Pl. 1, fig. 2, Polished section No. 404). All stages of conversion of magnetite into hæmatite can be detected.

Hæmatite is recognised under the microscope by its characteristically high reflective power, white colour and anisotropism and red internal reflexion. Polysynthetic twinning is often present. It may occur by itself in the midst of amorphous limonite, gœthite and psilomelane and also in polianite and pyrolusite and may show invasion and replacement by them. It is found in all stages of corrosion both by manganiferous and limonitic solutions, so that the size of the individual grains is variable. It may be found in fairly well-developed crystalline aggregates, as well as in irregular, rod-shaped, crescentic and partly rounded forms of varying sizes in the replacing media. Its relationship to other minerals is well brought out by etching, particularly in the case of a manganiferous (*i.e.*, pyrolusite-psilomelane) environment which turns black on treatment with $H_2SO_4+H_2O_2$, leaving the hæmatite unaffected (Pl. 1, fig. 3). In suitable sections it appears in parallel rows of grains and laths indicating the (?) bedding planes or planes of schistosity of the country-rock.

Frequently, it is found replacing magnetite along cleavage planes. Sometimes the marginal portions of the magnetite crystals are converted entirely into hæmatite, the central core remaining almost unaffected, while the intermediate portion is a zone of replacement in varying degrees. Such phenomena of martitisation of magnetite are well-known.

The minerals described so far may be called the original mineral-constituents of the mother-rock. Judging by these minerals, the replaced rocks seem to be magnetite-hæmatite-quartzites and biotite-quartz schists.

Secondary ore minerals.

The metasomatic minerals formed during the lateritisation of the country-rock are the following :—

Limonite, pseudomorphous after hæmatite.

Colour.—Dark grey, almost like braunite.

Reflectivity.—Decidedly lower than that of hæmatite.

Crossed nicols.—Feeble anisotropism which is sometimes masked by its intense red internal reflection ; sometimes a closely spaced triangular pattern is observed.

The limonite has exactly the same external form as that of hæmatite described above, and occurs in the midst of amorphous limonite and gœthite as well as psilomelane, polianite and pyrolusite, being also replaced by them. Under high magnification (oil-immersion), remnants of magnetite are found in the mineral, having the same relationship as in hæmatite. At first sight the limonite appears like hæmatite with unreplaced magnetite-remnants in it, but its reflectivity, especially under oil-immersion, is decidedly less. The triangular pattern observed under crossed nicols is reminiscent of the structure of magnetite-hæmatite intergrowths where hæmatite has largely replaced magnetite along its octahedral cleavage planes.

It would appear that hæmatite which originally replaced magnetite has itself been pseudomorphed by limonite, preserving the original internal structure. Magnetite seems to be unaffected by the process of limonitisation. These limonite pseudomorphs are also often found as inclusions in the manganiferous minerals, being undoubtedly earlier than the amorphous limonite and gœthite which are described below.

Limonite, amorphous. This is the commonest product of "lateritisation' and forms the bulk of the ores.

Colour.—Dark grey with a reddish mauve tint.

Reflectivity.—Lower than that of the above-mentioned mineral, almost as low as quartz.

Crossed nicols.—No anisotropic effect, but appears porous, and shows the characteristic red and sometimes orange-yellow internal reflection, especially noticeable along the margins.

Hardness.—Lower than that of the above-mentioned mineral, but higher than that of gœthite.

It occurs in fairly large, irregular and amorphous masses, is porous, and varies in reflectivity from place to place. It is largely veined and replaced by gœthite and the manganese minerals (*vide* Pl. II, figs. 3 and 5, Polished section No. 405).

Gœthite—

Colour.—Dark grey like amorphous limonite but perceptibly lighter.

Reflectivity.—Slightly higher than that of above.

Pleochroism.—Noticeable.

Crossed nicols.—Anisotropic in dark greys with red to orange internal reflection.

Hardness.—Lower than that of the above-mentioned mineral.

It is decidedly later than the amorphous limonite, and is found veining the latter (Pl. II, fig. 3). Its time sequence with regard

to the manganiferous minerals is variable, being sometimes immediately post-limonite and pre-manganese-ore, sometimes post-manganese, as it is found veining as well as replacing all the manganese-ores and is associated with chalcedony. This chalcedony is discernible in hand-specimens and is usually brown in colour, due to a large admixture of wisps of gœthite. In polished sections these two minerals appear in concentric zones and present the usual 'gel' structure.

Polianite and pyrolusite—

Colour.—White with a yellowish tinge.

Pleochroism.—Noticeable.

Reflectivity.—High.

Crossed nicols.—Characteristic mauve, blue and yellow colour.

Polianite, in polished sections, is sometimes characterised by a marked brass-yellow colour, noticeable even to the unaided eye. It occurs in larger masses and is harder than pyrolusite. It is fairly abundantly developed and among the manganese-minerals is next in importance to pyrolusite and psilomelane. The polianite crystals are large and idiomorphic, often with regular cleavage-planes arranged perpendicular to the direction of elongation. (Pl. I, fig. 4). The cleavage-planes may not always be well-marked, but show up well on etching. Undulatory extinction is sometimes observed.

The mineral is sometimes found occurring in the druses in psilomelane and limonite, and is definitely of surface origin. Sometimes it is as early as psilomelane, the two having been deposited simultaneously. It may also be replaced by later colloform psilomelane (Pl. I, fig. 4, Pl. II, figs. 1 and 2, Polished section No. 406).

Pyrolusite has been observed in several generations. Sometimes one vein crosses and displaces an earlier vein of the same material in psilomelane and limonite. The acicular crystals of these veins are arranged perpendicular to the vein-walls; not all the crystals extinguish simultaneously, so that under crossed nicols, the structure simulates polysynthetic twinning. Pyrolusite also commonly occurs in alternate rings with colloform psilomelane, gœthite and chalcophanite.

Psilomelane—

Colour.—White

Reflectivity.—High but variable, and lower than that of pyrolusite.

Crossed nicols.—Isotropic.

Easily darkened by 1 : 1 HCl, with development of widely spaco triangular markings.

It is largely developed and occurs in more than one generation. The earliest type, which is probably simultaneous with polianite, is more or less homogeneous in texture and in reflected light, the whitest of the different varieties; only remants of this early psilomelane is preserved, the mineral having been considerably replaced by pyrolusite, chalcophanite and gœthite.

The later generations of the mineral vary considerably in hardness and brightness, preserve the colloform structure, and may occur in cavities in polianite (Pl. I, fig. 4) and limonite. Liesegang rings with alternate bands of psilomelane, chalcophanite and other manganese minerals are common (Pl. II, fig. 4, Polished section No. 407).

Psilomelane, component 3 of Schneiderhohn—

Colour.—Grey white, almost like that of psilomelane in low power objective.

Reflectivity.—As high as psilomelane, but lower in the direction of absorption.

Pleochroism.—Best seen under oil-immersion, grey-white to reddish-brown.

Crossed nicols.—Anisotropic effect is very high, between greyish white to reddish grey white.

HCl, conc. does not act so readily on the mineral as on psilomelane.

It is evidently a late mineral and occurs with the later developed colloidal psilomelane in solution-cavities in polianite or in vugs in limonite, in the latter occurrence alternating with psilomelane and chalcophanite. It is present in very fine needles and is best observed under higher magnifications. Droplets of psilomelane show, under high magnification, the presence of numerous small radiating or sub-parallel needle-like crystals in certain zones. It may form the outer rim of psilomelane (Pl. II, figs. 1 and 2); it has also been found to occupy the central portions of the spherules.

Chalcophanite—

Colour.—Grey with a tinge of light violet; varies in polarised light between dark violet grey and light grey;

Reflectivity.—Maximum when needles or flakes have long axes parallel to the nicol; in this position reflectivity is slightly lower than that of polianite; maximum absorption is at right angles, and reflectivity is almost as low as that of the gangue minerals.

Crossed nicols.—Strong anisotropism, colour varying between white and greyish with violet tinge.

Hardness.—Fairly soft and is easily scratched.

This is one of the last manganiferous minerals to form, replacing psilomelane and veining limonite and gœthite (*vide* Pl. II, figs. 3 and 5). It also forms alternating rings with psilomelane (Pl. II, fig. 4), indicating that the two minerals originated practically simultaneously from solutions alternating in chemical composition. In these rings, the crystals are aligned with their long axes perpendicular to the channels.

Sometimes chalcophanite forms spherulitic and sheaf-like flaky aggregates in cavities in limonite. It is generally found as an alteration product of franklinite, usually accompanied by another secondary mineral, hetærolite. In the ores studied, however, neither of these two minerals has been found. As in the case of the purely manganiferous minerals, this zinc-manganese mineral is of surface origin. Beyond the fact that these minerals have been derived from percolating waters, microscopical examination has not so far elicited any evidence as to the actual source from which the materials have been derived.

VIII. ORIGIN.

A. Microscopic evidence.

An examination of the sections makes it clear that the country-rocks composed of gneissic granites and mica-schists were subjected to processes of extensive metasomatic replacements in three successive stages in the following order, *viz.*, (1) limonitisation or replacement by more or less purely ferruginous solutions accompanied by the hydration of pre-existing iron-minerals, leading to the formation of amorphous limonite, (2) manganiferous and ferruginous replacements, *i.e.*, replacements by psilomelane and polianite and contemporaneous gœthite, and (3) manganese-zinc and ferruginous replacements, *i.e.*, pyrolusite-psilomelane-chalcophanite-gœthite formation with contemporaneous chalcedony.

The processes may be described as follows :—

(1) *Limonitisation.*—Under this is included the formation of abundant amorphous limonite due to weathering and to the influx of ferruginous solutions. Much of the iron was probably derived from the ferruginous constituents of the rocks. This stage represents the earliest of the supergene alterations, since remnants of limonite are found embedded in, and veined by, psliomelane and polianite, and also gœthite and chalcophanite. In no case has it been found

to be later than the minerals named; on the other hand, it seems to be a good deal earlier than the secondary minerals, as its disposition is in all cases discordant with those of the secondary minerals.

In addition to the amorphous type, there is a pseudomorphic type (pseudomorphic after hæmatite). There is no clear evidence as to the relative ages of the pseudomorphic and amorphous types. The former is found embedded in the latter suggesting that the pseudomorphous type is the earlier of the two. It may however have arisen at the same time as the amorphous type; the conversion of hæmatite to limonite implies hydration and there is no reason why the conversion might not have been brought about by the same solution that was precipitating the amorphous variety around it. It is of course possible that hydration took place at an earlier stage, in which case its age would be earlier than that of the amorphous variety.

(2) *Manganiferous and ferruginous replacements.*—Coarsely crystalline polianite and psilomelane, showing little or no colloidal structure, were the next group of minerals to be formed by replacement of the primary minerals of the country-rock as well as of the amorphous limonite. They are accompanied by fairly coarsely crystalline gœthite. In places, gœthite has formed earlier, being found next to limonite walls in the veins, the manganiferous minerals occupying the central portions of the veins. The manganese minerals of this generation are highly corroded and replaced by the minerals of the next generation.

(3) *Manganese-zinc-iron replacements.*—Pyrolusite, psilomelane with psilomelane component 3, chalcophanite, some gœthite and chalcedony formed at this stage. These minerals invariably show colloidal structures and occur in veins and druses in the earlier minerals, often replacing them, and following more or less the fractures and bands occupied by the minerals of the preceding stage. This is probably indicative of the time interval of the two stages being not so very great as that between the first and the second stages. [The minerals may occur in alternate bands indicating their successive and alternate precipitation from solution varying in composition from time to time.]

The advent of zinc with manganese and iron is confined to this stage. The source of zinc like that of the manganese is unknown as no zinc-bearing primary mineral has been detected in the country-rock. Some of the manganese of this stage was no doubt derived

from the manganese minerals of the earlier stage. The introduction of zinc into the ores is characterised by the advent of a fairly large amount of chalcedony and gœthite in an exceedingly fine form.

B. Field evidence and general discussion.

The source of the manganese is obscure. The lateritised zones occur in a country of granitic gneiss containing bands and streaks of mica-schist. These as well as basic igneous rocks seem to have been subjected to alteration and replacement. Partly limonitised fragments of amphibole-schist were found in the band south-west of Phasimal. Though none of these local types of rocks have been chemically analysed to determine their iron and manganese content, they do not appear to be in any way abnormal.

It is well-known that igneous and metamorphic rocks contain some manganese, the average for igneous rocks being 0·124 per cent. of MnO, or 0·10 per cent. of Mn[1] according to F. W. Clarke and H. S. Washington, and 0·098 Mn according to Hevesy and others.[2] The element is contained mainly in some of the ferruginous, titaniferous and aluminous silicates such as biotite, chlorite, amphibole, garnet, etc. Manganese is invariably accompanied by much iron, the proportion of Mn to Fe being roughly 1 : 100 in acid rocks and 1 : 30 in basic rocks.[3] From the above figures it can be computed that 1 kilogram of Mn may be derived from the dissolution of 1 ton of average igneous rock, or from 3 to 4 tons of granitic rock, since the latter contains smaller amounts than intermediate and basic rocks.

As we have seen, the manganese-ore is found in close association with limonite in zones which run parallel to the schistosity of the country rock. These zones are covered by forest and their junction with the surrounding rocks is obscured by a thick mantle of ferruginous soil. The occurrence of brecciated quartzite cemented by chalcedonic silica seems to indicate that lateritisation has occurred in shear-zones. Such zones should have constituted excellent channels for the circulation of meteoric waters which, it is suggested, dissolved the manganese and iron contents of the surrounding rocks and precipitated them in these zones. The limonitisation of these

[1] F. W. Clarke, Data of Geochemistry. *U. S. G. S. Bull.* 770, p. 29, (1924); Clarke and Washington. The Composition of the Earth's Crust. *U. S. G. S. Professional Paper* 127, (1924).

[2] G. von Hevesy, A. Merkel and K. Wurstlin. Die Haufigkeit des chroms und Mangans. *Zeits. f. anorg. Chem.* 219, p. 192, (1934).

[3] W. J. Vernadsky. Geochemie in ausgewahlten Kapiteln. p. 61, Leipzig, 1930.

zones is therefore thought to be due not merely to lateritic weathering but in a large measure to replacement of the country rock by circulating waters.

Manganese goes into solution as bicarbonate and less commonly as sulphate or phosphate.[1] Carbonic, sulphuric and humic acids help in dissolving the manganese and iron content of the rocks. The bicarbonate is probably the most common form in ground waters. Iron is precipitated from these waters by oxidation and aeration in a slightly acid environment while the manganese comes down in an alkaline environment.[2] Iron and manganese oxides (and hydrates) are precipitated under oxidising conditions, aided perhaps by the presence of living organisms which are held by many authorities[3] to play an important part in manganese deposition. The minerals formed under oxidising conditions are wad, pyrolusite, polianite and psilomelane, some of the precipitates being colloidal in nature.

Manganese is generally accompanied by small amounts of Ca, Ba, Zn, Cu, Co, K and Li in addition to the dominant iron. Some of the oxides of these elements are probably absorbed by the colloidal iron-manganese precipitates. Moreover it is known that Fe, Mn, Mg and Zn (divalent elements) can to some extent take the place of each other in isomorphous relationship as they have more or less similar atomic dimensions.[4]

The minerals found in these deposits—limonite, gœthite, pyrolusite, polianite, psilomelane and chalcophanite—indicate formation at ordinary temperatures and pressures. Some of them show colloform and banded structures. These fit in well with the hypothesis of deposition from ground waters of vadose nature. This does not necessarily mean that the manganese and iron were derived from the rocks in the immediate vicinity. They may have been brought in from some distance by ground water in circulation.

Field evidence is in accord with the microscopic evidence as to the age relationship of the minerals. As already mentioned, the limonite masses are traversed by veins of manganese minerals.

[1] W. Lindgren. Mineral Deposits. p. 280-81, 4th edition, New York, 1933.

[2] Carl Zapffe. The deposition of Manganese. *Econ. Geol.* XXVI, pp. 799-832, (1931); Catalysis and its bearing on the origin of Lake Superior iron-bearing formations. *Econ. Geol.* XXVIII, pp. 751-772, (1933).

[3] *See* W. J. Vernadsky. Geochemie in ausgewahlten Kapiteln. p. 71 *et seq.* Leipzig, 1930.

[4] W. J. Vernadsky. *Loc. cit.*, p. 64.

The cavities are lined by concentric layers deposited from water. The nodules in the soil represent replaced fragments of rocky material or segregation of ore in concretionary and botryoidal shapes, during the course of continued weathering of the lateritised zones.

Numerous examples can be cited as illustrations of deposits of residual and bedded iron-manganese ores which are regarded as having been laid down by water. These include replacement lodes and pockets, bog iron-ore and wad, and segregations of manganese nodules in the sea-bottom.[1] Residual deposits of manganese of lateritic origin have been described from different parts of India by Sir L. L. Fermor.[2] The deposits described in the present paper may be considered as having the characters of both lateritic and metasomatic ones.

IX. PROSPECTS OF WORKING THE DEPOSITS.

Low grade of ore.

The analyses given in a previous section show that the ores vary from manganiferous iron ores (Mn 5 to 30 per cent. and Fe 30 to 65 per cent.) to ferruginous manganese-ores (Mn 25 to 50 per cent. and Fe 10 to 30 per cent.) in the nomenclature adopted by Fermor. All of them contain a considerable amount of iron, and the total of iron *plus* manganese averages 55·4 per cent. In only one case does the manganese content exceed 35 per cent., which would be classified as a manganese-ore in the U. S. A., but not in India (*see Rec. Geol. Surv. Ind.*, LXX, p. 221, 1935). The area certainly contains better ore, but it would be difficult to collect quantities of such ore for purposes of marketing. The average deduced from the analyses given above will be about 25 per cent. Mn and 31 per cent. Fe.

It is very doubtful whether a market can be found at present for such a low grade ore, especially as large quantities of ore of high grade (with over 48 per cent. Mn) are still produced from the mines in Central Provinces and Vizagapatam.

[1] Beyschlag, Vogt and Krusch (Translated by Truscott). Deposits of useful minerals and rocks, London, 1916. Pp. 812-869 (Metasomatic Iron and Manganese lodes); pp. 982-1000 (Lake and bog ores); pp. 1099-1108 (Manganese-ore beds).

H. D. Miser. *U. S. G. S.*, Bull. 734.

E. C. Harder. The iron ores of the Appalachian region in Virginia. *U. S. G. S.* Bull. 380, p. 215.

[2] L. L. Fermor. Manganese-ore deposits of India. *Mem. Geol. Surv. Ind.*, XXXVII, pp. 380-389, (1909).

With regard to the quantities obtainable from the deposits i Bamra, it has already been mentioned that the ore is distribute in an erratic fashion in the debris and soil o the lateritised zones. So far as known, th best results were got from the eastern slopes of the hill near Khairdih where the yield was about 90 lbs. of 30 per cent. ore per cubic yar of earth. At other places the yield will be much less, down t almost nothing but slightly manganiferous limonite or lateritise rock. In this band, especially between Pukhura and Krimaloi, few hundred tons of ore can be expected. This is of course a mer guess, since it will be necessary to carry out detailed prospecting for arriving at a reliabl estimate of the quantities present in each band.

Low yield.

Prospecting necessary.

The Pukhura-Krimaloi area is at a distance of about 20 mile from the nearest stations on the Jharsuguda-Sambalpur branch o the Bengal-Nagpur Railway, while the Jamunkira area is about 10 miles further away. From the rail-head to Calcutta the distance is 330 miles. Should it be possible to find a remunerative market for the ore, the deposits can be worked by quarrying on a small scale with the local labour. The ore will in most cases require breaking up and hand-picking, so as to improve the grade by rejecting the siliceous portions and limonite, but it is believed that it will be difficult to bring the manganese percentage even up to 40 per cent. without rejecting far too much of the material.

Transport facilities.

Perhaps the best way of utilising the deposits will be to work the limonite as well as the ferruginous manganese-ore so that the whole can be used as a manganiferous iron-ore, in which case the tonnage available will be considerably increased and economic working will be possible under normal conditions. Such a course however will not be possible until there is a demand for ferruginous manganese-ore containing, say 5 to 15 per cent. manganese.

INDEX.

MGIPC—M—VIII-1-13—13-1-41—725.

EXPLANATION OF PLATES

PLATE I.

FIG. 1. Quartz (white) being replaced by manganese-ore (Thin section No. 26,638). $\times 24$, ordinary light.

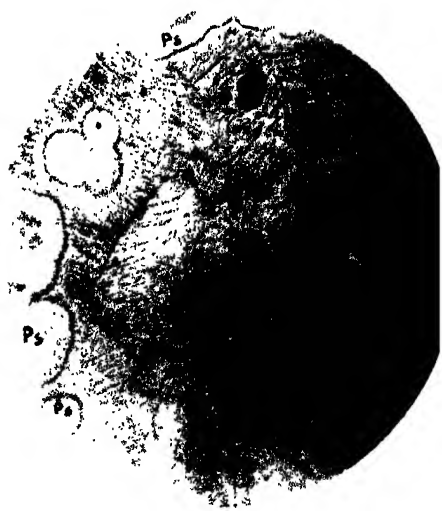
FIG. 2. Magnetite (dark grey) replaced along octahedral cleavages by hæmatite (light grey). Polished section No. 404. $\times 450$, reflected light

FIG. 3. Hæmatite, showing twinning, embedded in polianite and psilomelane (appearing dark owing to treatment with etching reagents). Polished section No. 404. $\times 450$, reflected light, crossed nicols.

FIG. 4. Polianite (marked by cleavage) replaced by colloform psilomelane. Polished section No. 406. $\times 46$, reflected light.

FIG. 1. QUARTZ (WHITE) BEING REPLACED BY MANGANESE ORES (BLACK).
× 24, ordinary light.

FIG. 2. MAGNETITE REPLACED ALONG OCTAHEDRAL CLEAVAGE-PLANES BY HÆMATITE (WHITE). × 450, reflected light.



P K Ghosh, Photomicros *G S. I. Calcutta.*

FIG. 3. HÆMATITE, SHOWING TWINNING, EMBEDDED IN ETCHED MANGANESE MINERALS (DARK).
× 450, × nicols, reflected light.

FIG. 4. POLIANITE (P) REPLACED BY COLLOFORM PSILOMELANE (Ps).
× 46, reflected light.

PLATE II.

FIG. 1. Enlarged view of a portion of Fig. 4, Pl. I, showing a remnant of polianite, replaced by amorphous psilomelane with psilomelane component 3 (appearing as bright radial needles along the margin of amorphous psilomelane). Polished section No. 406. ×184, reflected light, crossed nicols.

FIG. 2. Shows spherical bodies of psilomelane with a rim of psilomelane component 3, replacing polianite. Polished section No. 406. ×184, reflected light, crossed nicols.

FIG. 3. Amorphous limonite (L) veined and replaced by gœthite (G), psilomelane and *chalcophanite* (C) in turn. Chalcophanite further veined by psilomelane. (*See* also fig. 5). Polished section No. 405. ×37, reflected light, crossed nicols.

FIG. 4. Pyrolusite in the core is followed by several bands of amorphous psilomelane of varying powers of reflectivity, and then by alternate rings of chalcophanite (dark) and psilomelane in Liesegang ring fashion. Polished section No. 407. ×37, reflected light.

FIG. 5. An enlarged view of a portion of Fig. 3, showing highly birifringent chalcophanite (C) with a central vein of psilomelane (dark), veining gœthite (G), psilomelane (P) and limonite (L), the last mentioned mineral being the earliest of all. Polished section No. 405. ×184, reflected light, crossed nicols.

FIG. 1 POLIANITE (CENTRAL) REPLACED BY PSILOMELANE AND PSILOMELANE COMPONENT 3
× 184, reflected light, × nicols

FIG. 2 PSILOMELANE WITH MARGINAL RIM OF PSILOMELANE COMPONENT 3 IN POLIANITE
× 184, reflected light, × nicols

FIG. 3 AMORPHOUS LIMONITE (L) VEINED AND REPLACED BY GOETHITE (G), PSILOMELANE AND CHALCOPHANITE (C)
× 37, reflected light, × nicols

FIG. 4 PYROLUSITE FOLLOWED BY PSILOMELANE (P) BANDS, CHALCOPHANITE (C) ETC.
× 37, reflected light

FIG. 5 CHALCOPHANITE (C) WITH VEIN OF PSILOMELANE (P_1). VEINING PSILOMELANE (P_2), GOETHITE (G), THE LAST TWO VEINING LIMONITE (L)

RECORDS

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PROFESSIONAL PAPER No. 9.

THE CAMBRIAN FAUNA OF THE SALT RANGE OF INDIA.

BY W. B. R. KING. (With Plates 1-5.)

GENERAL INTRODUCTION.

The collection consists of a large number of fossils from the locality at Kusak (32° 42′ 30″ : 73° 4′) from which Mr. Middlemiss obtained the fossils described in 1901 by Redlich.

This part of the collection enables additional information to be obtained regarding the trilobite *Redlichia*, but the brachiopods have been so fully dealt with by the late Dr. Walcott in his monograph on Cambrian Brachiopods that there seems to be little to add to his description.

The other localities from which identifiable fossils have been obtained are N.E. and E.N.E. of Chittidil Rest House (32° 29′ : 71° 54′)—here some new trilobites have been found which are described in the sequel.

The brachiopods from these localities appear to belong to forms already described from India and re-described and figured in detail by Walcott.

The specimens from Chhidru (32° 33′ : 71° 46′) are in a poor state of preservation, and do not appear to justify description.

From Khewra (32° 38′ : 73° 1′) specimens of *Neobolus* have been obtained, but these do not show any new features and so have not been refigured.

Discussion regarding the Salt Range Cambrian succession has been published by Mr. E. R. Gee in 1934 and in this there is a bibliography of the papers dealing with the stratigraphical succession.

The following gives a list of the localities with the forms which have been identified : –

Kusak Fort Hill. (K33/589).

Redlichia sp.
Neobolus warthi Waagen.
Hyolithes wynnei Waagen.

Kusak Fort Hill. (K33/590-592).

Redlichia noetlingi (Redlich).
Botsfordia (*Mobergia*) *granulata* (Redlich)

1,000 yds. N.E. of Chittidil Rest House.

(K33/594 and Types 17264-67).

Chittidilla plana gen. & sp. nov.
Ptychoparia sakesarensis sp. nov.

900-1,000 yds. E.N.E. of Chittidil Rest House.

(K33/595 & Types 17256-63).

Ptychoparia geei sp. nov.
Ptychoparia sakesarensis sp. nov.
Lingulella wanniecki Redlich.
Botsfordia (*Mobergia*) *granulata* (Redlich).

1¾ m. S.E. of Chhidru. (K33/671-72).

? *Lingulella wanniecki* Redlich.

Khewra gorge. (K33/674-675).

Neobolus warthi Waagen.

Nilawan. (K33/676).

Neobolus warthi Waagen.
Hyolithes wynnei Waagen.

DESCRIPTION OF SPECIES.

TRILOBITA.

Order OPISTOPARIA.

Family *REDLICHIIDAE.*

REDLICHIA Cossman.

Redlichia noetlingi (Redlich).

Plate 1, figs. 1-3, Plate 3, figs. 1-9 and Plate 4, figs. 1-10.

Hoeferia noetlingi Redlich, *Pal. Ind.*, 1901, both var., *angusta* and var., *lata*.

Redlichia noetlingi (Redlich): Cossmann, *Rev. Critique Palæozool.*, 1902, p. 52.

Redlichia noetlingi (Redlich): Reed, *Pal. Ind.*, 1910.

Redlich's original description of this form (Redlich, 1901, p. 3) under the name *Hoeferia noetlingi* gives the main features of the species, but some additional information is now available. Some 30 good specimens of cranidia are in this collection, most of them show some signs of distortion although the rock in which they are preserved is a mudstone with no obvious signs of cleavage developing.

It has been found that by measuring all the available good cranidia and plotting the results, some interesting figures are obtained.

It appears that the average breadth of the glabella at the posterior glabella furrow is 62 per cent. of the length of the glabella. Similarly taking the average of the angle between the pre-ocular part of the facial suture and the axial direction we get an angle of 64° (angle α of Saito, 1934, p. 219). (*See* text-figure 1.)

In the abundant material now available there is every gradation from the short stumpy glabella to the narrow elongated form, which suggests that the vars. *lata* and *angusta* of Redlich's original description may be better interpreted as distortion of the specimens belonging to the same form by compression of the rock either parallel to, or at right angles to, the axial direction of the cranidium.[1]

[1] Whitehouse (1939, p. 188) points out that he has chosen Plate I, fig. 1 of Redlich as the lectotype. The re-examination of the type material shows that this specimen is the only one which can be identified with certainty and the present study shows that both names var., *angusta* and *lata* must be abandoned.

If we take these average measurements as representing the probable dimensions of the original cranidium, we get an outline as

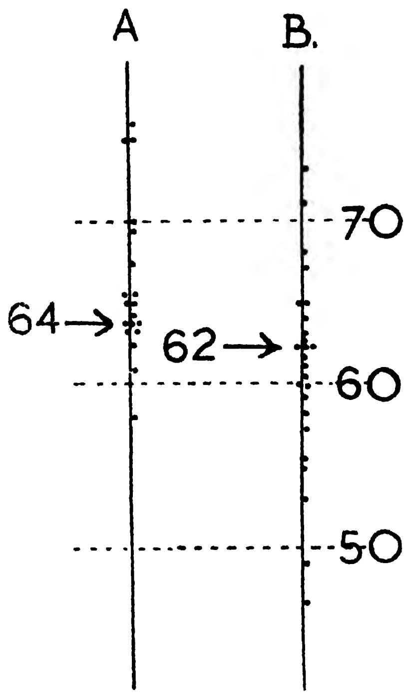

FIG. 1.—A. Values for angle α from specimens showing both right and left margins of the preglabellar field. Value $\frac{2\alpha}{2}$ plotted giving an average of 64°. B. Breadth/Length ratio for glabella $\frac{B \times 100}{L}$ giving a value of about 62 : 100 for the probable dimensions of the glabella.

in text fig. 2*a*. This outline was drawn on a piece of soft draughtsman indiarubber (*a*) with the axial direction along the length of the rubber, and (*b*) at 30°, 45° and 60° to the length. The rubber was then subjected to slight compression in a vice, and the text figures 2*b*-*g* are drawings of the deformed outline so obtained. The

figure in the right hand top corner was a square before deformation and shows the slight amount of compression which was used.

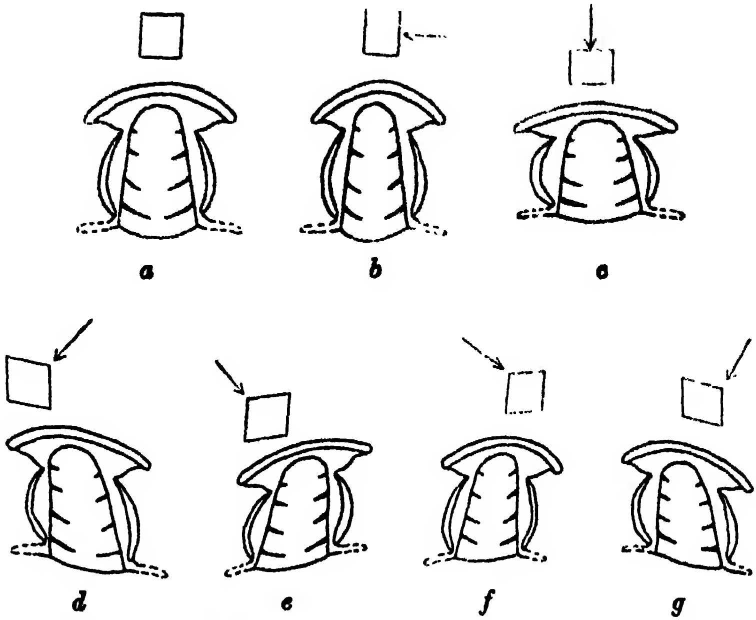

FIG. 2.—*a*. Undistorted cranidium drawn from average measurements.
b. Compressed parallel to axis.
c. Compressed at right angles to axis.
d. & *e*. Compressed 45° to axis.
f. Compressed 30° to axis.
g. Compressed 60° to axis.

It will be seen that these outlines agree in a remarkable way with the specimens figured in Plates 3 and 4.

One rock fragment has two cranidia, one on each side of the fragment. In one there is fairly complete symmetry, but the cranidium is of the short stumpy type of the var. *lata* with angles of value of about 85°—80° to the axial line for the pre-ocular course of the facial suture (angle α) (Plate 4, fig. 3). The other specimen (fig. 4) lies with its glabella at an angle of about 40° to the first (but on the other side of the rock). This shows a distorted cranidium tending towards the var. *angusta* type with angle α of 75° on the one side which is preserved. Clearly here the form is controlled by the direction in

which the cranidia lie in relation to the direction of compression in the rocks.

In studying the rest of the material representing this species, the shape of the free cheeks can be determined with some certainty. There are several points where the additional material supplements Redlich's figures and diagrams. The best preserved specimens show an absolutely continuous curve of the outer margin of the cheek with the genal spine, whereas Redlich's restoration (*op. cit.*, Plate 1, fig. 8) shows a distinct outward bend of the spine at its junction with the cheek. Secondly, the margin is strengthened by a strong doublure which continues the curve of the margin anteriorly on the under side of the cheek as a spike. The section of the margin is flat on the dorsal surface and rounded on the ventral side.

Redlich notes that this margin is "longitudinally striated". This is true in general although in detail the striæ at the actual margin are not parallel to the margin but directed slightly inwards anteriorly. The genal spine is oval in cross section and on it the striæ turn into short marked rugosities nearly deserving to be called blunt spinelets. They are arranged much as the scales on the cone of a fir tree.

One point which has given much trouble is the course of the post-ocular part of the facial suture. On the cranidia figured by Redlich this is not shown but in the reconstruction the wing-like extension of the cranidium along the posterior margin is shown by dotted lines and the position of this part of the facial suture was undoubtedly obtained from a study of the free cheeks.

In the abundant material now available for study, only two specimens have been found which show this narrow lateral extension of the posterior part of the cranidium, all the others appear to have a post-ocular facial suture which runs nearly straight down to the posterior border. This is deceptive, and is probably due to fracture for a study of the free cheeks supports the evidence of the two specimens regarding the presence of the lateral extension.

A number of the cranidia show a row of definite pits in the furrow which separates the pre-glabellar field from the anterior rim (see Plate 3, fig. 6). This agrees with what was found in the specimens of *Redlichia* from Persia (King, 1930).

There are some twenty well preserved free cheeks. The thickened border, with its doublure is continuous with the genal spine, and with the outer half of the posterior margin. That the doublure

is continued beyond the genal spine is well seen in one of Redlich's specimens figured by him (1901, Plate I, fig. 3) and refigured here (Plate 3, fig. 4) and also seen in the specimen (Plate 4, fig. 10). At the point where the raised border and doublure end, at some little distance posterior to the genal spine, the posterior margin of the free cheek takes a sharp bend of about 70° so that for some distance it runs at right angles to the main axis of the trilobite before it rises sharply to the base of the ocular area. This latter part corresponds with the apparent base of the fixed cheek as seen in the great majority of specimens.

In his discussion of *R. chinensis*, Saito states "the post-ocular course of the suture is unknown, but it is likely that it is represented by the margin OX, text-fig. 1", *i.e.*, he assumes that it runs out, in a similar way to that in which it appears to do in *R. noetlingi*, although in some other species of *Redlichia* the post-ocular course is short and runs directly backwards. An examination of Mansuy's (1912) excellent plates of *R. chinensis* (=*R. mansuyi* Resser and Endo), supports Saito's suggestion.

This feature emphasises the close relationship between *R. noetlingi* *R. chinensis* and *R. mansuyi*.

At the point where the suture reaches the posterior border, however, there is a marked change in the direction of the posterior margin of the cephalon which is well shown in Redlich's reconstruction (Plate 1, fig. 8).

This is of considerable interest when the systematic position of *Redlichia* is considered, for, as Poulsen says (1927, p. 319) "*Redlichia* is, at any rate, the genus which shows the closest relationship to the Mesonacidæ, the most primitive family known". In the Mesonacidæ it is common to find a marked inter-genal spine, while in some species, *e.g.*, *O. grœnlandicus* (Poulsen, 1927, XIV, fig. 29), the main spine is situated in a position very similar to that on the free cheek of *Redlichia*. If the genal spine of *Redlichia* is homologous with the genal spine of the Mesonacids, and the angular bend in the posterior margin of the *Redlichia* cephalon is homologous with the inter-genal spine of certain olenellids, it would appear to strengthen the relationship of the two families and to suggest that the well formed suture of *Redlichia* points to the probable position of the undeveloped sutures of *Olenellus*; that is, in the position Poulsen considers most likely. (See also Whitehouse, 1939, p. 188.)

Thorax.—Only scattered isolated pleuræ are preserved, but a number of strong spines are found similar in every way to the genal spines only symmetrically spreading out into a funnel-shaped area. A few of these are attached to the axial part of a thoracic segment (Plate 1, fig. 1). In two cases the spine and axial ring are joined to a short pleura with the normal spined termination. The shortness of the pleural part suggests that it was one of the posterior segments. This agrees with the observations of Saito and Mansuy on other species of *Redlichia*.

The pleuræ are obliquely grooved and end in sharp backwardly directed spines (Plate 4, figs. 6-7) which vary much in length according to their position in the thorax. In one specimen the spine is seen to be formed of a dorsal and ventral part, the latter being the doublure (Plate 1, fig. 3). This gives a flattened hollow structure which, when broken from the rest of the pleura, might easily be mistaken for a specimen of an Hyolithid.

Since the time of Redlich's description of the first species of the genus under the name *Hoeferia noetlingi*, a number of new species have been described. Of these the nearest to the Indian form is *R. nobilis* as noted by Walcott, who states that it is "closely related to *R. noetlingi*", the only differences being minor proportions of the glabella, while Saito states that the main difference is that in *R. nobilis* the palpebral lobe does not reach the glabella, while in *R. noetlingi* and *R. chinensis* it is only separated by the furrow.

The chief difference from *R. chinensis* is in the angle α made by the pre-ocular course of the facial suture which is 90° in *R. chinensis*, 75° for *R. nobilis* and 64° for *R. noetlingi* and 45° for *R. coreanica*.

Recently several new species of *Redlichia* have been described by Resser and Endo from Eastern Asia. Some of the forms originally referred to *R. chinensis* by Mansuy and Walcott have been removed from that species to *R. mansuyi* by Resser and Endo (1937, p. 282). This form has much in common with *R. noetlingi*. The Australian form described by Foord (Etheridge Jr., Ms.) under the name *Olenellus forresti* in 1890, has many similarities to the Salt Range species. The angle α however is rather smaller, being about 50° to 45°. Dr. C. J. Stubblefield is working on some new Australian material and comparisons between the forms from the two areas will, no doubt, indicate further features of similarity and difference. He has given me much help in studying this collection.

The question of the age of the Redlichia beds is discussed by Saito and the writer agreed with his opinion (King, 1937, p. 5), that they should be placed in the lower part of the Middle Cambrian. This opinion is expressed by Dr. Walcott when redescribing the brachiopods. Dr. Whitehouse (1939, p. 264) however still retains the *Redlichia* stage in Australia in the Lower Cambrian although he states that the Australian horizon is "equivalent to an early part of the *Redlichia* sequence, as developed in Asia" (p. 265). It has been thought advisable to refigure the original specimens described by Redlich since his drawings are considerably restored.

The specimens from the Neobolus Shales of the Chittidil localities belong to species of *Ptychoparia* and an allied genus here named *Chittidilla.*

The position of *Ptychoparia* has always given much trouble in Cambrian Palæontology, for authors have interpreted it in diverse ways, some using it in an extremely wide sense, while others have tended to split it up in numerous new genera. Reed (1910, p. 13) devotes several pages to the subject, but retains a large series of species in the genus. Walcott (1913, p. 130) also included many species in this genus, but pointed out that he has included forms with relatively long palpebral lobes. Similarly many North American species have been referred by various authors to the genus *Ptychoparia.*

Recently, however, there has been a tendency, particularly by Resser in America, and Kobayashi in Japan, to refer the American and Asiatic forms to newly erected genera.

Undoubtedly it is advantageous to refrain from lumping unrelated forms together into one genus, but on the other hand faunal similarity of widely separated regions may be masked by giving a new generic name to a form largely because it is from a different geographical area.

The main difficulty with *Ptychoparia* appears to be that when dealing with simple types which conform to the common unspecialised Middle Cambrian pattern it is doubtful what reliance can be placed on minor variations in the relative dimensions of the various parts, and it often appears that there is nearly as much variation between the different species of some of these newly erected genera as between the various genera themselves.

The forms from Chittidil appear to be very near even the most restricted definition of the genus *Ptychoparia* based on the type *Pt. striata* Emmerich.

The fact that all authors admit that forms which cannot be distinguished from *Ptychoparia* have been found in the Pacific Middle Cambrian province, does appear to justify retaining that general name for many of the Indian species.

In making comparison with Reed's (1910) *Ptychoparia* from Spiti, a difficulty arises in that the Spiti fossils are all crushed and deformed, and it would seem to be better to erect a new species rather than make what is possibly a false identification which would tend to carry an exact correlation of the beds in the two areas.

If however these forms are moved from *Ptychoparia* they must be placed in or very near Whitehouse's new genus *Lyriaspis* from the Middle Cambrian of Australia (Whitehouse, 1939, p. 202). It may be noted that Whitehouse places the Spiti species *Pt. spitiensis* and *Pt. stracheyi* of Reed in his new genus.

TRILOBITA.

Order OPISTOPARIA.

Family *PTYCHOPARIIDAE.*

Genus PTYCHOPARIA.

Ptychoparia geei sp. nov.

Plate 1, figs. 6 and 7.

Description.—Body oval flattened.

Cephalon.—Almost exactly semi-circular extending beyond the thorax at the angles, just twice as wide as long. Genal angles with flat stout spine reaching to 4th or 5th thoracic segment.

Cranidium.—Glabella slightly elevated above the rest of the cranidium, tapering sub-conical with rounded anterior margin; ratio of length to width between 1·3 and 1·5 to 1. Glabellar furrows, three in number well marked at the margins but not extending across the glabella; posterior pair directed backwards at an angle of about 45°. The middle furrow directed only slightly backwards, and the anterior furrow short and either running straight into the glabella or directed slightly anteriorly in a few specimens.

The fixed cheeks, flat, 2/3 width of glabella at the palpebral lobes, pre-glabellar field slightly convex, separated from well marked narrow

frontal margin by a well defined but shallow groove. Frontal margin somewhat upturned and convex, wider in centre than at edges. The pre-glabellar field is separated from the fixed cheeks by a well marked eyeline which joins the glabella halfway between the anterior glabella furrow and the anterior end of the glabella.

Palpebral lobes small. The course of the facial suture is similar to that found in *Ptychoparia striata*. It rises first at right angles across the posterior margin of the cephalon and swings inward to run practically straight to the palpebral lobe at an angle of 45° to the posterior margin.

From the palpebral lobe it runs almost parallel to, or diverging slightly from the axial line till it meets the furrow separating the anterior margin from the pre-glabellar field where it turns sharply and passes obliquely across the anterior margin.

The free cheeks show a flattish thickened border only slightly marked off from the centre of the cheek. The anterior corner shows the oblique crossing of the rim by the facial suture and the posterior part is produced into a strong flat genal spine.

Thoracic segments.—A slightly tapering axis which at the third segment occupies about 2/9th of the total width of the body—number of segments unknown—probably not less than 12.

Pleuræ narrow, and faintly grooved, ending in short posteriorly directed spines.

Pygidium. Small, lens-shaped; axis well defined about 5 rings visible; lateral parts 4 segments visible; margin entire.

Measurements of type—

Cephalon—	
Height	11 mm.
Width	22 mm.
Glabella (including neck ring)—	
Length	8 mm.
Width	5 mm.
Cranidium width at palpebral lobes	11·5 mm.
Thorax at 3rd body ring	21 mm.
Axis at 3rd body ring	4 mm.

Most of the specimens of cranidia measure approximately 10 × 15 mm.

The material consists of one more or less complete cephalon with eight body rings attached. There are also several fully grown cranidia and in the collection there are a few isolated pygidia which probably belong to this species.

All the specimens are preserved in a fine maroon-coloured mudstone with micaceous partings and thin grey bands.

The specimens appear to be flattened, but show no signs of distortion like the *Redlichia* of Kusak.

From the stratigraphy the horizon cannot be far removed from the *Redlichia* horizon of Kusak, although no signs of *Redlichia* itself have been seen. The characteristic *Botsfordia* (*Mobergia*) of that horizon, however, does occur with other brachiopods on the same slabs as the *Ptychoparia*.

Ptychoparia sakesarensis sp. nov.

Plate 1, figs. 8-9 and Plate 2, figs. 1-4.

Associated with *Pt. geei* is a closely related form with a more quadrate cranidium and glabella.

Description.—Cranidium, general appearance square. Width at eyeline almost exactly equals the length along the medial axial line. Frontal border only slightly curved, frontal rim widest at central point separated from pre-glabellar field by shallow furrow (specimens tend to break along this furrow).

Pre-glabellar field slightly inflated, marked from the fixed cheeks by a well defined eyeline which starts a little below the top of the glabella, and runs slightly backwards to a small palpebral lobe. The two branches of the pre-ocular facial suture converge only very slightly as they run forward to the anterior margin.

The small palpebral lobes are situated half way between the anterior and posterior margins. The post-ocular part of the facial suture runs back to the posterior margin at an angle of 40° to the axial line.

Glabella with straight sides converging slightly anteriorly, truncated by gently curving anterior margin. Glabella slightly raised above general level of the cranidium. Three pairs of glabellar furrows, each reaching about ¼ across the glabella. Posterior pair directed slightly backwards. Neck ring fairly well defined.

This form differs from *Pt. geei* in the more quadrate shape of the whole cranidium, and also in the shape of the glabella, which here is a truncated cone while in *Pt. geei* more parabolic in outline.

The material consists of a number of cranidia, both mature and small immature specimens, all preserved in maroon shale and thus probably somewhat flattened. It is difficult to compare these speci-

mens with the form called *Conocephalites warthi* by Waagen but as will be seen from the photograph of this specimen (Plate 1, fig. 4) it should probably be referred to the same genus as *Ptychoparia sakesarensis* though perhaps not to the same species.

Since *Pt. sakesarensis* and *Pt. geei* occur associated it is difficult to say which isolated free cheeks belong to which species.

Chittidilla plana gen. and sp. nov.

Plate 2, figs. 5-8.

Description.—Cranidium consists of slightly tapering glabella, with three pairs of glabellar furrows faintly visible stretching about 1/3 way across the glabella and directed slightly posteriorly. Neck ring well developed with short posteriorly directed blunt spine. Fixed cheeks wide, nearly flat, pre-glabellar field slightly arched and reaching without a furrow to the anterior margin, thus it makes one feature with what must be the frontal rim. Pre-glabellar field divided from the fixed cheeks by a nearly horizontal eyeline which joins the glabella a little behind its anterior margin.

The facial suture rises abruptly from the posterior margin, and after crossing the posterior furrow swings in towards the glabella; at the posterior end of the palpebral lobe the fixed cheek is nearly as wide as the glabella at this level. The palpebral lobe is not very inflated subtending about the middle 1/3 of the length of the glabella. From the anterior end of the lobe the facial suture runs practically straight forward to the margin diverging only a few degrees.

A free cheek associated with these cranidia shows a strong genal spine and the forward bend of the anterior course of the facial suture at the anterior margin.

Associated thoracic segments are poorly preserved, but appear to end in a blunt spine rather than being rounded.

Dimensions of type—

Length of cranidium	7·5 mm.
Breadth of cranidium at posterior margin	11·4 mm.
Breadth of cranidium at palpebral lobes	8·2 mm.
Length of glabella from neck ring	3·7 mm.
Width of glabella at neck ring	3·5 mm.
Distance from glabella to anterior margin	2·4 mm.

These fossils are associated with brachiopods at K33/594 in the shales "near the top of the Magnesian sandstone series", 1,000 yards N. E. of Chittidil Rest House.

There are 5 cranidia and a few isolated fragments. They differ from most other types in the fusion of the pre-glabellar field and the anterior rim. This is a rare feature in Middle Cambrian trilobites, and appears to justify the erection of a new genus to accommodate these forms. They clearly belong to the Ptychopariid stock.

Horizon.—At Spiti the horizon yielding the numerous *Ptychoparia,* described by Reed appears to be definitely in the Middle Cambrian while in China similar Ptychopariids are said to be found both in the Lower Cambrian and Middle Cambrian (Walcott, 1913), but since the work of Saito shows that all the *Redlichia* horizons of Korea are above the *Protolenus* zone, it may be necessary to move some of the beds formerly classed as Lower Cambrian up into the Middle Cambrian.

In the Salt Range the Ptychopariids here described come from "near the top of the Neobolus Shales" and also from "purple grey shales near the top of the Magnesian Sandstone series".

The present collection would seem to group these into one palæontological horizon of the Middle Cambrian, but probably quite low in that division.

Note on the type of *Olenus indicus* Waagen.

Little can be added to the description or figures of this specimen given by Waagen (1889, Plate I, fig. 3) and photographed here (Plate 1, fig. 5) but there can be little doubt that the specimen cannot be referred to *Olenus.* From a comparison with Asiatic trilobites described in recent years it would appear that this specimen should be placed with or near the genus *Blackwelderia* of Walcott. In this genus many species have similar large irregularly spaced pustules on the glabella and fixed cheek, but until more material and particularly pygidia are found no accurate reference to any genus can be made.

The specimen does however suggest a Middle Cambrian rather than an Upper Cambrian horizon for the beds in which it was found.

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EXPLANATION OF PLATES.

PLATE 1.

Redlichia noetlingi (Redlich).

FIG. 1.—Short pleura attached to axial ring with long spine. G. S. I. No. K33/591 *p*.

FIG. 2.—Axial ring with spine. G. S. I. No. K33/591 *q*.

FIG. 3.—Cast of pleura showing doublure. G. S. I. No. K33/591 *r*.

FIG. 4.—*Ptychoparia warthi* (Waagen) Photograph of type of *Conocephalites warthi* Waagen. *Pal. Indica* Series, XIII, Vol. IV, Plate I, fig. 1, (1889.) G. S. I. Type No. 4/112.

FIG. 5.—*Olenus indicus* Waagen, *Pal. Indica*, Series XIII, Vol. IV, Plate I, fig. 3, (1889) ? *Blackwelderia*. G. S. I. Type No. 4/114.

Ptychoparia geei sp. nov.

FIG. 6.—Type specimen from tributary gorge about 900-1,000 yds. E. N. E. of Chittidil Rest House, Salt Range. 32·29′: 71·54′ Near the top of the Neobolus Shales. G. S. I. Holotype No. 17256.

FIG. 7.—Cranidium. Same locality. G. S. I. Type No. 17257.

Ptychoparia sakesarensis sp. nov.

FIG. 8.—Cranidium. Type specimen. Same locality and horizon as *Pt. geei* G. S. I. Holotype No. 17258.

FIG. 9.—Another cranidium with small immature cranidium touching it at the left palpebral lobe. G. S. I. Type No 17259.

All figures ×2.

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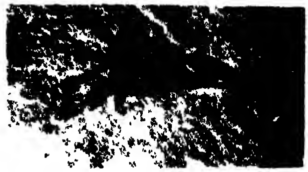

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CAMBRIAN FAUNA OF THE SALT RANGE OF INDIA.

All figures (× 2).

G. S. I., Calcutta

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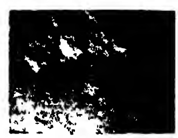

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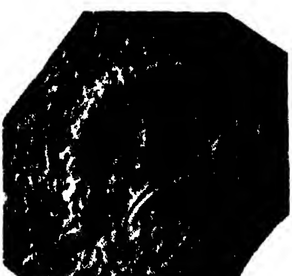

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CAMBRIAN FAUNA OF THE SALT RANGE OF INDIA.

All figures (× 2).   *G. S. I. Calcutta*

PLATE 2.

Ptychoparia sakesarensis sp. nov.

FIG. 1.—Pygidium. G. S. I. Type No. 17260.

FIG. 2.—Small immature cranidia probably belonging to this species. G. S. I. Type No. 17261.

FIG. 3.—Small cranidium. Same locality. G. S. I. Type No. 17262.

FIG. 4.—Free cheek belonging to either *Pt. sakesarensis* or *Pt. geei*. Same locality. G. S. I. Type No. 17263.

Chittidilla plana gen. et sp. nov.

FIG 5.—Type specimen from gorge about 1,000 yds. N. E. Chittidil Rest House. From purple shales near the top of the Magnesian Sandstone Series. G. S. I. Holotype No. 17264.

FIG. 6 & 7.—Cranidia. Same locality. G. S. I. Type Nos. 17265 and 17266.

FIG. 8.—Free cheek and pleural fragments. Same locality. G. S. I. Type No. 17267.

All figures ×2.

PLATE 3.

Redlichia noetlingi (Redlich).

FIG. 1.—Photograph of type specimen figured by Redlich, *Pal. Indica* New Series, Vol. I. Pl. I, fig. 1, (1901). G. S. I. Type No. 7/232.

FIGS. 2 & 3.—Other specimens used by Redlich, *Pal. Indica*, New Series, Vol. I. Pl. I, figs. 8 and 2. G. S. I. Type Nos. 7/239 and 7/233.

FIG. 4.—Free cheek figured by Redlich, *Pal. Indica*, New Series, Vol. I. Pl. I, fig. 3, (1901). G. S. I. Type No. 7/234.

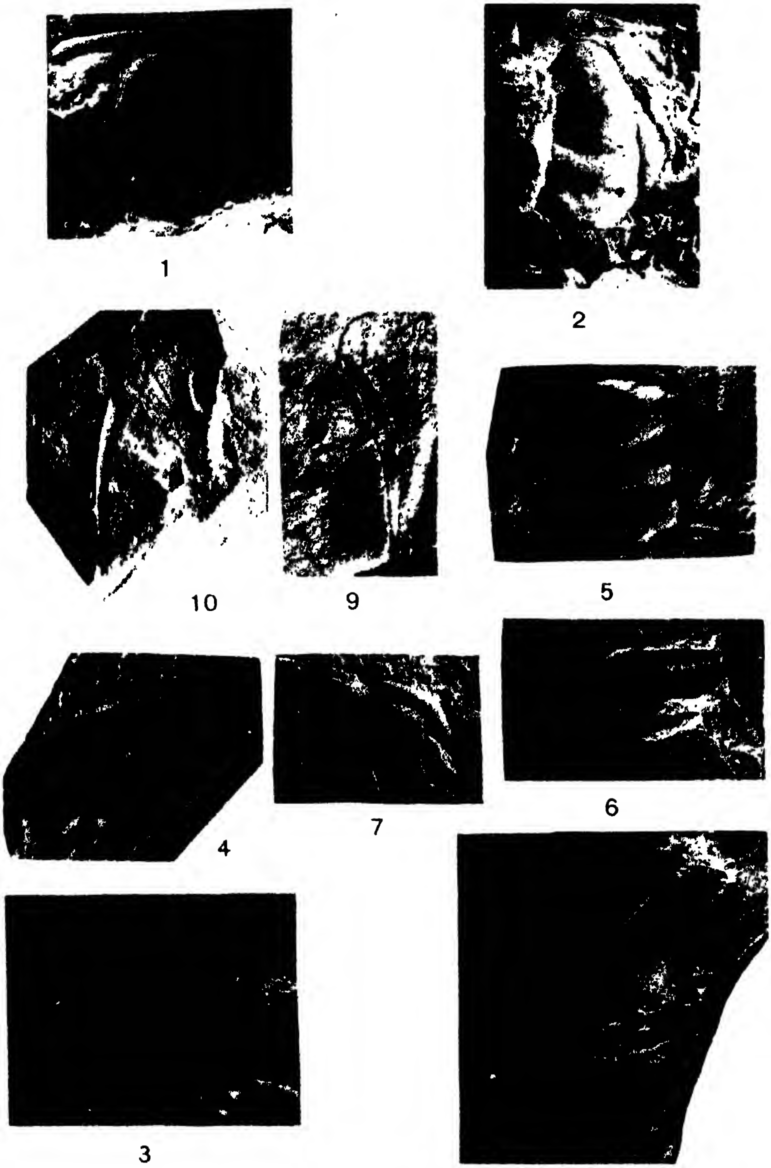
FIGS. 5-9.—Cranidia showing distortion due to different amounts and directions of compression. G. S. I. Nos. K33/591*a-e*.

All figures ×2.

CAMBRIAN FAUNA OF THE SALT RANGE OF INDIA

GEOLOGICAL SURVEY OF INDIA.

Records Vol LXXV   Plate 4.   Professional Paper. No 9



CAMBRIAN FAUNA OF THE SALT RANGE OF INDIA.

All figures (× 2).   *G. S. I., Calcutta*

PLATE 4.

Redlichia noetlingi (Redlich).

FIGS. 1-3.—Cranidia showing distortion due to different amounts and directions of compression. G. S. I. Nos. K33/591*f-h*.

FIGS. 4 & 5.—Cranidia showing narrow extension of the posterior part of the fixed cheek. G. S. I. Nos. K33/591 *i-j*.

FIGS. 6 & 7.—Isolated pleuræ. G. S. I. Nos. K33/591 *k-l*

FIGS. 8 & 9.—Free cheeks. G. S. I. Nos. K33/591 *m-n*.

FIG. 10.—Cast of free cheek showing extent of doublure on outer part of posterior border. (See also fig. 4 above). G. S. I No. K33/591 *o*.

All figures ×2.

PLATE 5.

Sequence exposed in Kusak fort hill, Salt Range.